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FLOW CHARACTERIZATION OF THE  
TRISONIC GASDYNAMICS FACILITY  
USING A LASER VELOCIMETER

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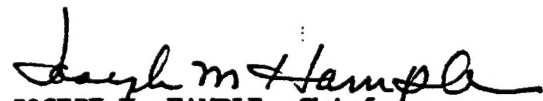
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## FOREWORD

This report was prepared by Clifford B. Weissman and George L. Seibert of the Aero-Optics Instrumentation Group, Experimental Engineering Branch, Aeromechanics Division, Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories. The work was performed in-house under project number 24041321 and covers the period July 1984 to February 1985.

This technical memorandum has been reviewed and is approved for publication.



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## TABLE OF CONTENTS

SECTION		PAGE
1.0	BACKGROUND . . . . .	1
2.0	SYSTEMS DESCRIPTION . . . . .	1
2.1	OPTICAL CONFIGURATION . . . . .	1
2.2	DATA ACQUISITION AND REDUCTION . . . . .	2
2.3	FLOW SEEDING . . . . .	3
2.4	TUNNEL POSITION MONITORING . . . . .	3
3.0	PROCEDURES AND RESULTS . . . . .	4
3.1	TESTING PROCEDURES. . . . .	4
3.2	BOUNDARY LAYER MEASUREMENTS . . . . .	4
3.3	FREE STREAM MEASUREMENTS. . . . .	5
4.0	CONCLUSION . . . . .	6
5.0	ACKNOWLEDGEMENTS . . . . .	7
6.0	REFERENCES . . . . .	8

# FIGURES

FIGURE		PAGE
1	TUNNEL GROWTH FOR 1 HOUR . . . . .	9
2	TUNNEL GROWTH FOR ENTIRE DAY . . . . .	10
3	SYSTEM CONFIGURATION IN THE TGF. . . . .	11
4—8	BOUNDARY LAYER SURVEYS. . . . .	12—16
9—10	TURBULENCE INTENSITY . . . . .	17—18
11—34	FREE STREAM CONTOURS . . . . .	19—42
35	SURVEY STATION . . . . .	43

## 1.0 BACKGROUND

The need for good tunnel calibration data is ever present for the experimenters. Current requirements by investigators in the Trisonic Gasdynamics Facility (TGF) have been including laser Doppler velocimeter (LDV) measurements more routinely. Therefore, a reasonable degree of confidence in the LDV measurements requires some baseline data from the facility with no model in the flow. To this end an entry was made the summer of 1984 exclusively for LDV analysis of the flow. The tunnel was run with the wooden nozzle blocks installed. Several Mach numbers were run for wall boundary layer and free stream measurements. In addition, during an entry in November 1984, several boundary layer profiles were taken at Mach 0.3 for comparison with the wood nozzle data, while the steel subsonic blocks were installed.

Hardware systems employed for the tests have been previously described [1-3]; however, for completeness they will be outlined in the next section. Additional information about the theory and application of LDVs can be found in the literature [4-7]. The flow seeding procedures as well as the tunnel position monitoring, and data acquisition and reduction methods have been improved and thus will be briefly described.

## 2.0 SYSTEMS DESCRIPTION

### 2.1 OPTICAL CONFIGURATION

The optical system consisted of a high power Ar ion laser operated in an all lines mode. For two-component velocity measurements, (axial and vertical) two strong wavelengths (blue and green) are split off and directed through a modular optical system. The first elements are beam splitters which are mounted orthogonally such that four beams now traverse the rest of the system. The next elements are Bragg cells which modulate one beam of each wavelength to; (1) eliminate directional ambiguity and (2) insure that a particle traversing the probe volume will produce an adequate number of cycles for the signal processors to validate datum. Next the beams traverse steering elements to insure proper crossing and beam expanders to limit the diameter of the probe

volume and increase the signal-to-noise ratio (SNR). A final focusing lens causes all four beams to cross and form the probe volume in which interference "fringes" are formed. As particles entrained in the flow traverse the probe volume, scattered light is collected and focussed into photomultipliers. The resulting output signal is cabled to the control room and analyzed by counter processors. The collection optics are oriented in an off-axis backscatter configuration. This enables all optical components to be mounted on a single three-axis computer controlled traverse table. The disadvantage of low signal-to-noise levels in backscatter is outweighed by the single traverse advantages.

## 2.2 DATA ACQUISITION AND REDUCTION

During the testing with the wood blocks installed, a microcomputer was used to gather the output digital data from the signal processors, control the traverse table, and read an optical position indicator. An on-line mean velocity value was computed and printed. The raw data was then transferred to a supermini computer for complete processing, analysis, and plotting. This was done because of the relatively slow computational ability and limited storage capacity of the microcomputer.

Recently a minicomputer has replaced the microcomputer enabling higher speed data acquisition and on-line data reduction. In addition, more data points can be taken and stored with the mini yielding a higher statistical confidence in the measurements. The mini was used during testing with the steel blocks installed. With the minicomputer, data was transferred from the TGF computer so that tunnel parameters were stored along with the LDV data for each test point. This enables the data to be normalized as flow conditions change during testing. Furthermore, histograms of the data can be obtained in a few seconds after data gathering is complete. The minicomputer has graphics capabilities so that the data may be plotted after testing in addition to being transferred to the supermini in final reduced form.

The data from the signal processors was input via direct memory access (DMA) which can accommodate data rates over 100,000/sec., compared to the micro where the maximum rate is about 2,000/sec. Since only one input port is

available for DMA input, a multiplexing coincidence detector (MCD) was fabricated to handle up to three channels of digital data from LDV signal processors. The MCD can be set to reject data from the signal processors if the arrival time of successive signals is outside of some window. The width of the window can be set from 1 to 100 microseconds. The MCD thus insures that data input to the computer from each processor originates from the same particle.

### 2.3 FLOW SEEDING

To obtain reliable LDV measurements, high quality particulates must be present in the flow in sufficient number to sustain rapid data acquisition. To this end, a sonic nozzle was installed in the tunnel stagnation section which atomized silicon oil. The seeder produces micron size particulates in the test section which covers a cylindrical cross-section of approximately six inches in diameter. Data rates (counts/second) can exceed 10,000 which is more than adequate for most testing in the facility. The disadvantage of the oil seed is the clean up required after testing to remove the residue from tunnel surfaces. Due to the relatively small diameter of the active area of the seed material, the position of the seeder must be moved when different areas of the flow are to be surveyed.

### 2.4 TUNNEL POSITION MONITORING

In order to insure that a data point is obtained at a specified axial position with respect to some reference, the relative position of the tunnel test section with respect to the LDV probe volume must be constantly monitored. Specifically, the entire test section can move upstream more than half an inch during a day of subsonic testing. Reference [3] describes an optical position indicator that was successfully used to correct the location of the probe volume to match the tunnel position. With the minicomputer, the output signal of the position indicator is processed by the data acquisition system which then automatically corrects the traverse position before a data point is taken. A time history of the tunnel position is shown in Figures 1 and 2. These curves show that the most significant change occurs during the first

hour of tunnel operation but never actually reaches equilibrium. Note also that the time scale begins at 20 minutes because this is approximately how long it takes from start up before data taking begins. Figure 3 shows a block diagram of the optical system, traverse, position indicator, seeding system, and data acquisition set-up at the TGF.

### 3.0 PROCEDURES AND RESULTS

#### 3.1 TESTING PROCEDURES

Before testing was begun, a daily check of optical alignment and traverse positioning was accomplished. Since modular optics were employed, very little or no adjustments were generally necessary. However, due to temperature variations and vibrations, daily correction to the traverse reference position was not unusual. Alignment with respect to the tunnel wall was accomplished by placing a small white card at the laser probe volume, allowing the beams to burn a small hole which was measured with an optical comparator. Thus the distance of the probe from the tunnel wall was known to within .002 inches.

Calibration constants (fringe spacings) for the LDV were first measured geometrically and verified by a calibration wheel. The calibration wheel consists of a steel disk with a fine wire mounted on the edge. The assembly is spun via a dc motor whose speed is controlled and monitored. Thus, knowing the diameter of the disk, the velocity of the wire through the probe volume is known to high accuracy [3]. Use of the calibration wheel also facilitates a quick check of the optical alignment for the LDV.

#### 3.2 BOUNDARY LAYER MEASUREMENTS

The boundary layer measurements were taken from the top wall of the test section because of the traverse limitations and optical access. Profiles were taken at several Mach numbers with the wood blocks and are shown in Figures 4-7. An unexpected feature of the plots is that the thickness of the boundary layers is several times that predicted by theory. The profile taken from the steel blocks shows a much thinner layer and this compares very well with theory. Figure 8 shows theory [8] versus data for the two nozzle configurations at Mach 0.3, and Reynolds number 1.7 million/ft. To use the boundary



layer code in Reference 8, both the position of the transition point from laminar to turbulent flow and the pressure distribution along the plate must be input to the program. Since the pressure distribution was not known, a constant pressure field and a transition point of 0.65 feet along the wall, which corresponds to a transition Reynolds number of about 1.1 million, were assumed. Because the code is designed for a sharp leading edge flat plate, only cursory agreement between the tunnel nozzle data and the code can be expected. A complete explanation for the discrepancy between the steel and wood data has not been formulated and is under discussion. The most probable contributing factors to the differences are the upstream histories and different pressure distributions along the walls. Figure 9 shows turbulence intensity versus vertical distance normalized by boundary layer thickness for two Reynolds numbers. Figure 10 shows normalized turbulence intensity versus boundary layer thickness at several Mach numbers. These plots show virtually no difference between the steel and wood wall data indicating that the increased boundary layer thickness was not caused by higher turbulence in the layer itself.

### 3.3 FREE STREAM MEASUREMENTS

For the free stream measurements, data was taken along the tunnel centerline at various axial positions and at several vertical and lateral stations. The data is presented (Figures 11-34) in a contour format so that an overall view of the flow can be observed. Figure 35 shows the geometrical location of the survey stations for the contoured data. This data is exclusively from the wood walls since comparable data with the steel walls was not taken. As in the case of the boundary layer data, the axial velocity component yields surprising results. The mean flow velocity along the centerline is several percent lower than the velocity off-centerline both vertically and laterally. This result is most probably due to three-dimensional effects from the side walls and nozzle boundary layer interactions. The vertical velocity component and turbulence intensities of both the axial and vertical components show a fairly flat distribution and appear well behaved. This is true for both axial versus lateral as well as the axial versus vertical contour plots.

#### 4.0 CONCLUSIONS

Instrumentation developments and data acquisition improvements have significantly enhanced the LDV utilization in the TGF. In particular, rapid acquisition of high quality data is becoming more routine. In addition, the programming of the minicomputer greatly reduces the possibility of operator error by simplifying data entry during testing, i.e. correcting the traverse position, entering coordinates, etc. The interface from the LDV to the facility computer will be vital to critical testing in the future and will enable some on-line analysis of the data.

Until further analysis of the data from the wooden nozzle blocks is accomplished, it is recommended that critical testing be done only with the steel blocks. Since both the free stream and boundary layer data are suspect, some standard probe data (Pitot and hot wire) should be taken to confirm the LDV findings. In addition, a more complete study using the improved LDV system may be in order.

## 5.0 ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of persons to this effort without whose participation the work could not have been accomplished. Mr. C. D. Miller for electronic developments and technical support during testing, Dr. J. Shang and Mr. J. Graham for use of the boundary layer code, and the TGF operations personnel.

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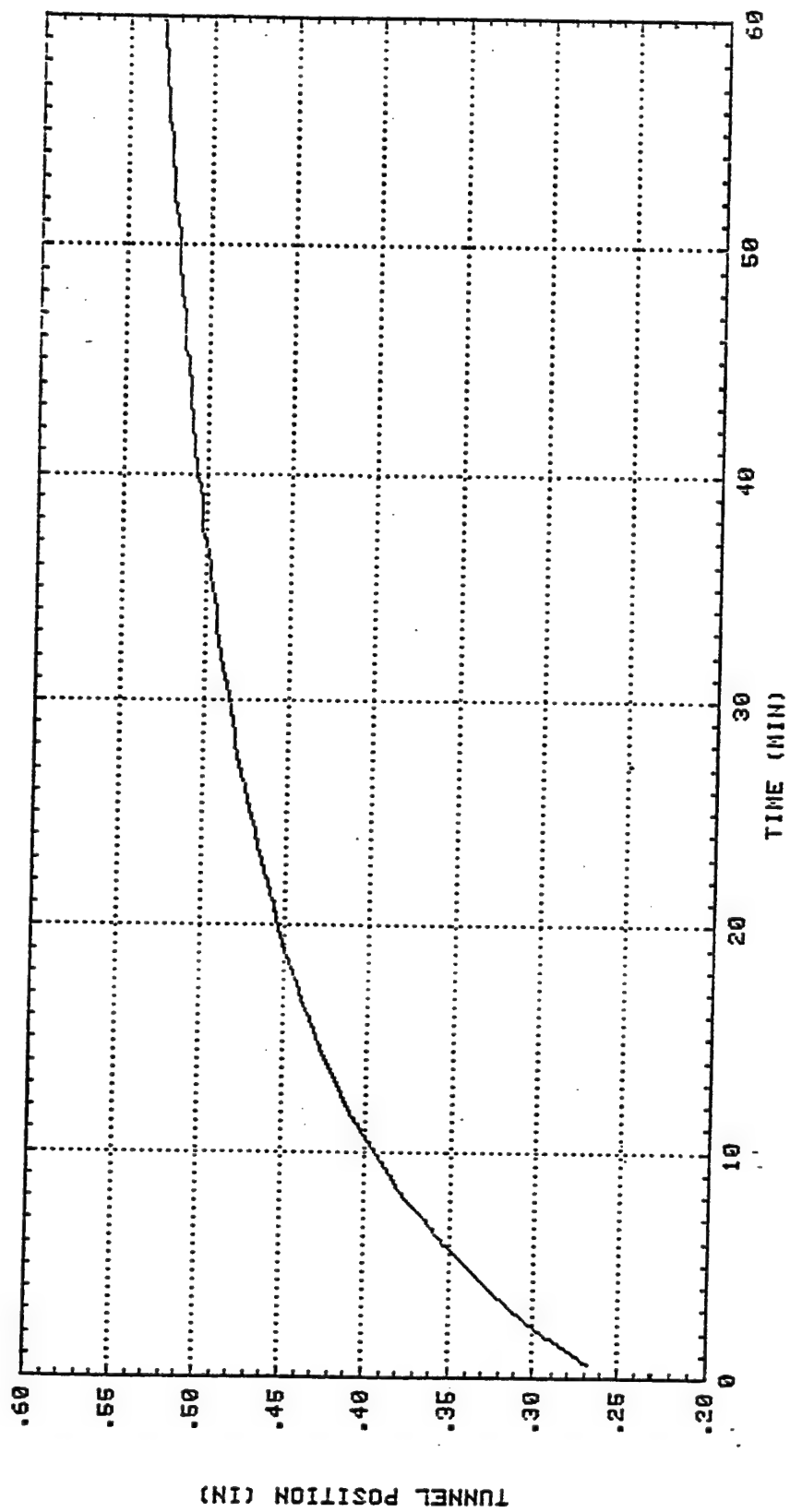


FIGURE 1. TUNNEL GROWTH FOR 1 HOUR.

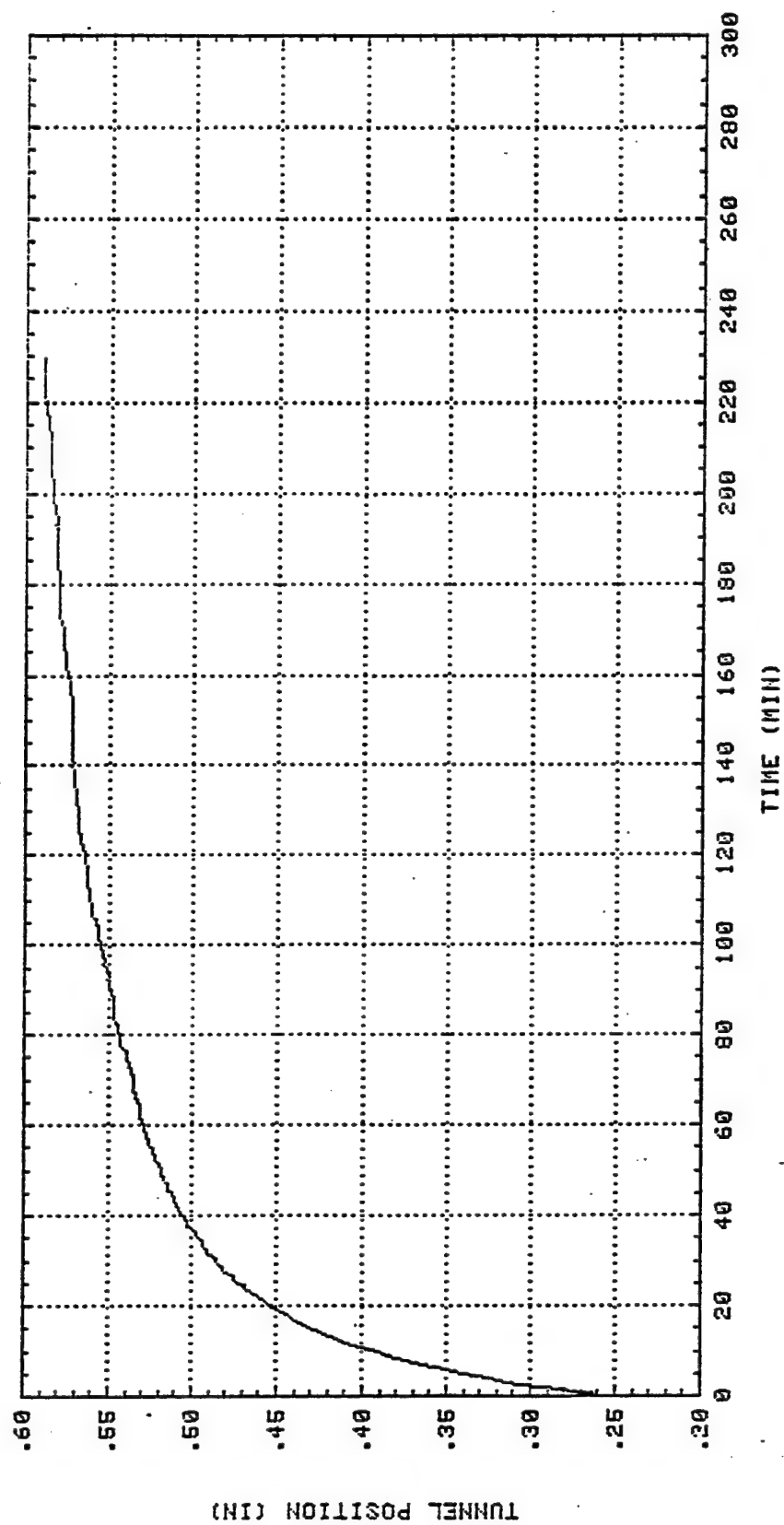


FIGURE 2. TUNNEL GROWTH FOR ENTIRE DAY

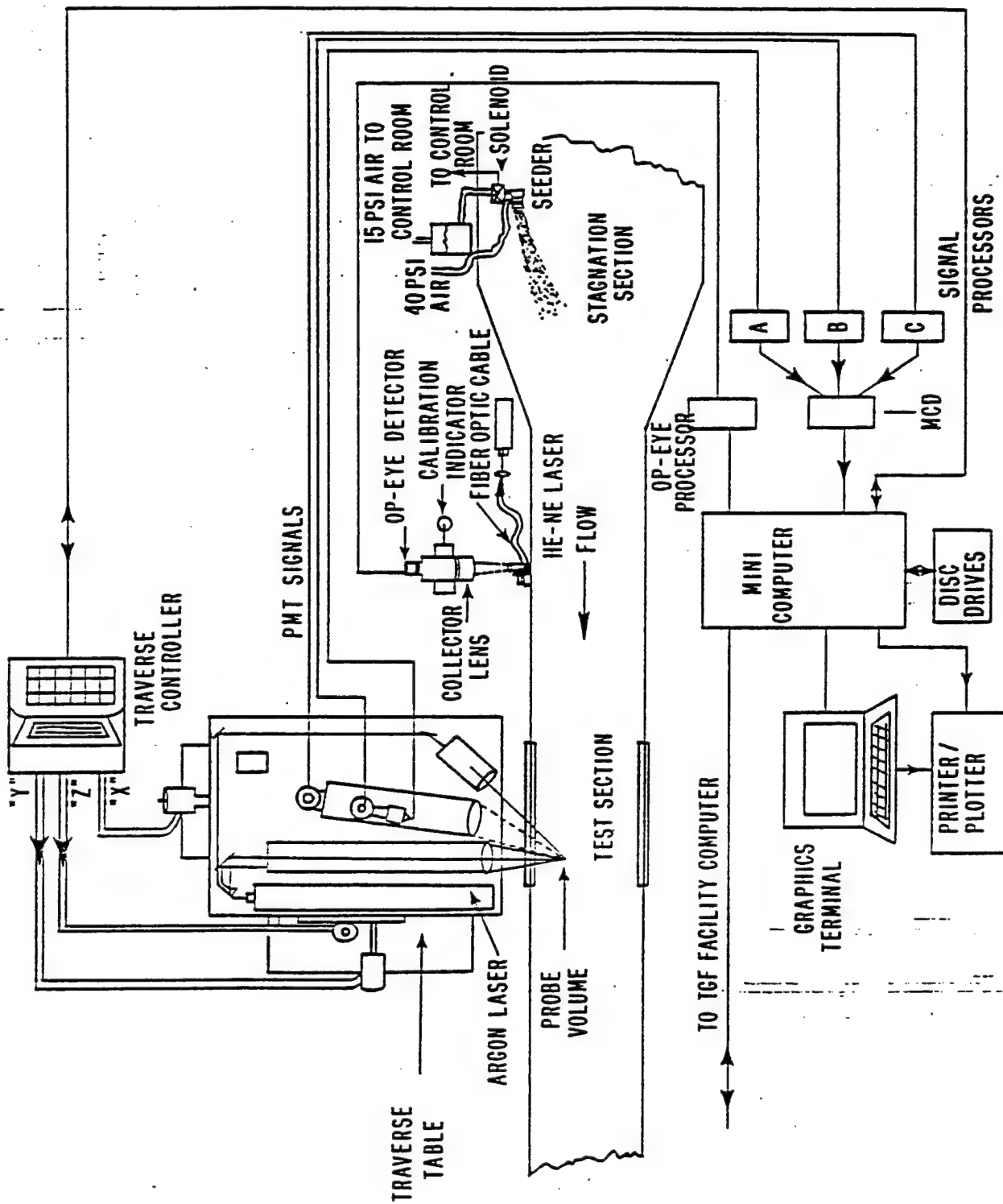


FIGURE 3. SYSTEM CONFIGURATION IN THE TGF.

# TGF LV BOUNDARY LAYER SURVEY

X-STATION=87.75 MACH 0.30 Re 1.70 MILLION/FT Y-STATION=0.00  
 $\delta^* = 0.3055$  INCHES

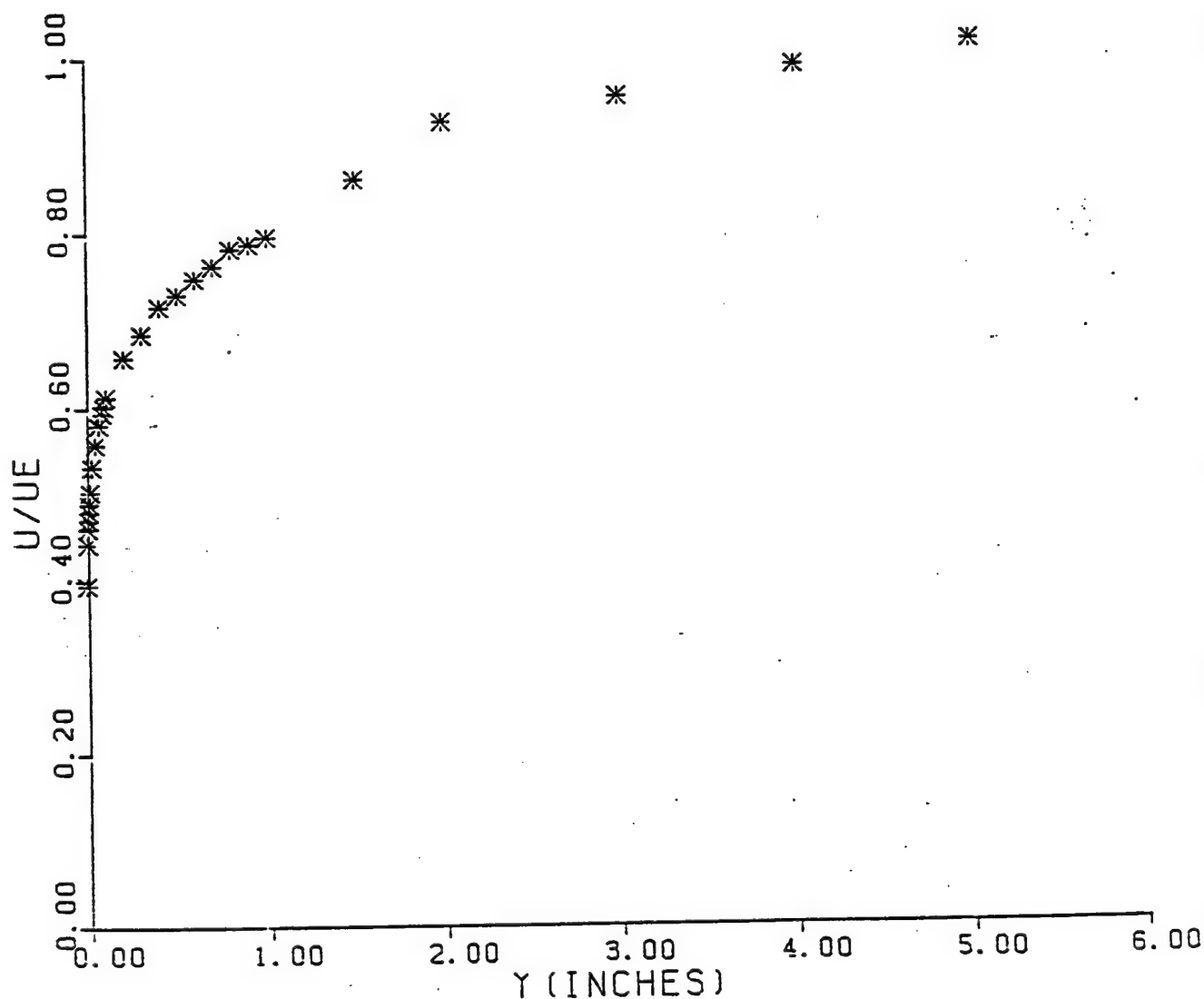


FIGURE 4. BOUNDARY LAYER SURVEYS



# TGF LV BOUNDARY LAYER SURVEY

X-STATION=87.75 MACH 0.50 Re 1.70 MILLION/FT Y-STATION=0.00

$\delta^* = 0.1965$  INCHES

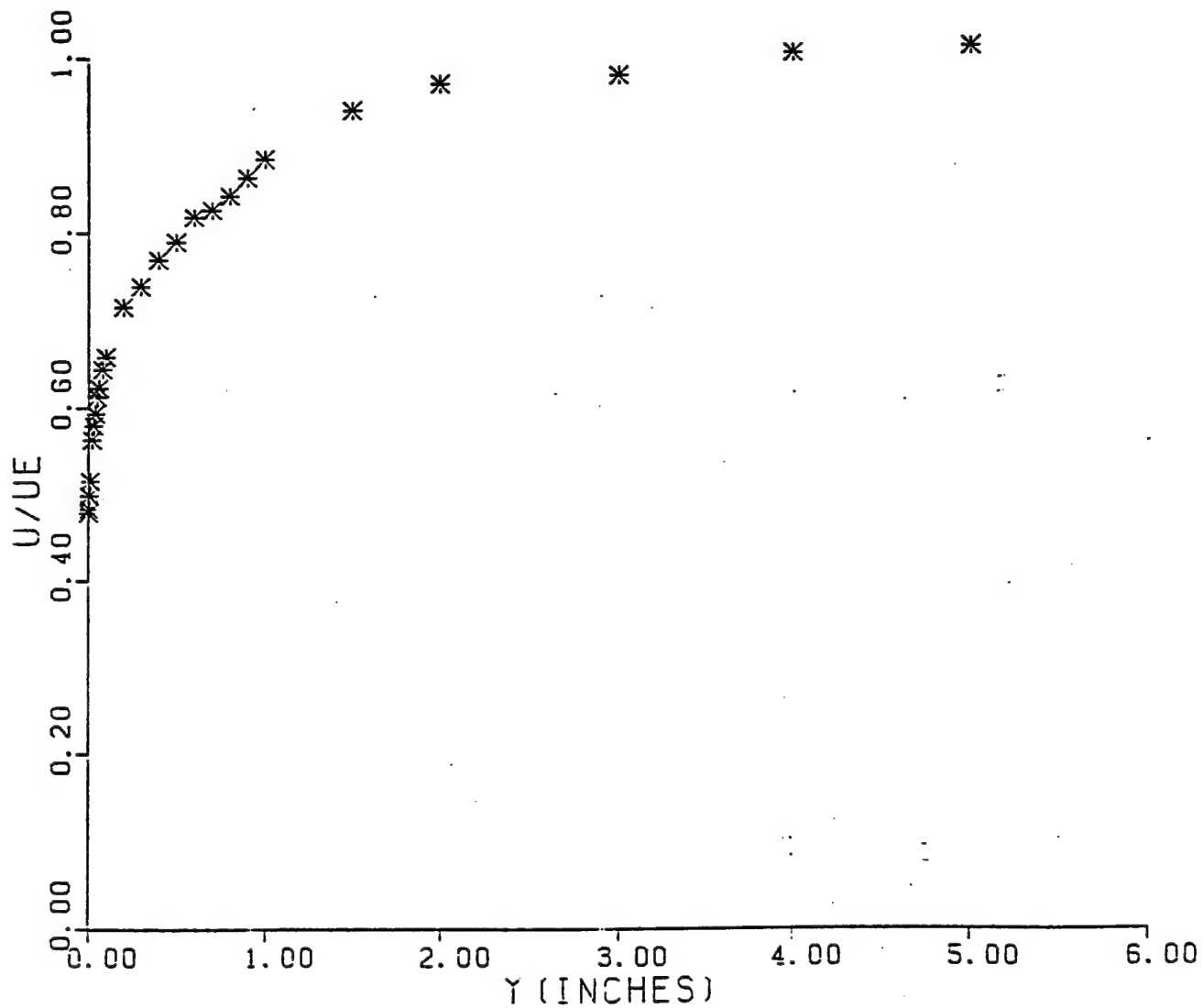


FIGURE 5. BOUNDARY LAYER SURVEYS

# TGF LV BOUNDARY LAYER SURVEY

X-STATION=87.75 MACH 0.60 Re 1.70 MILLION/FT Y-STATION=0.00

$\delta^* = 0.2416$  INCHES

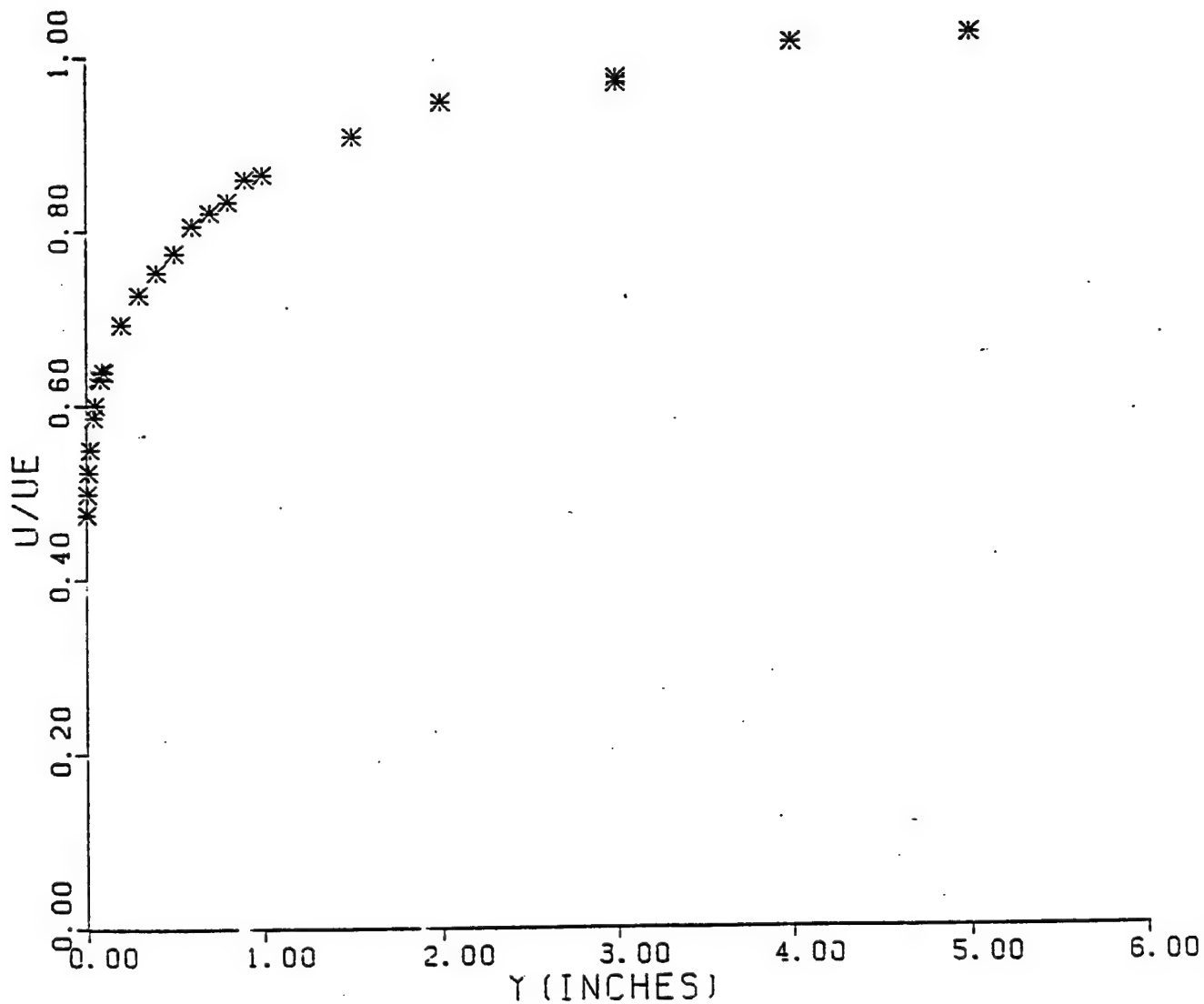


FIGURE 6. BOUNDARY LAYER SURVEYS

# TGF LV BOUNDARY LAYER SURVEY

X-STATION=87.75

MACH 0.80

Re1.70 MILLION/FT

Y-STATION=0.00

$\delta^* = 0.2285$  INCHES

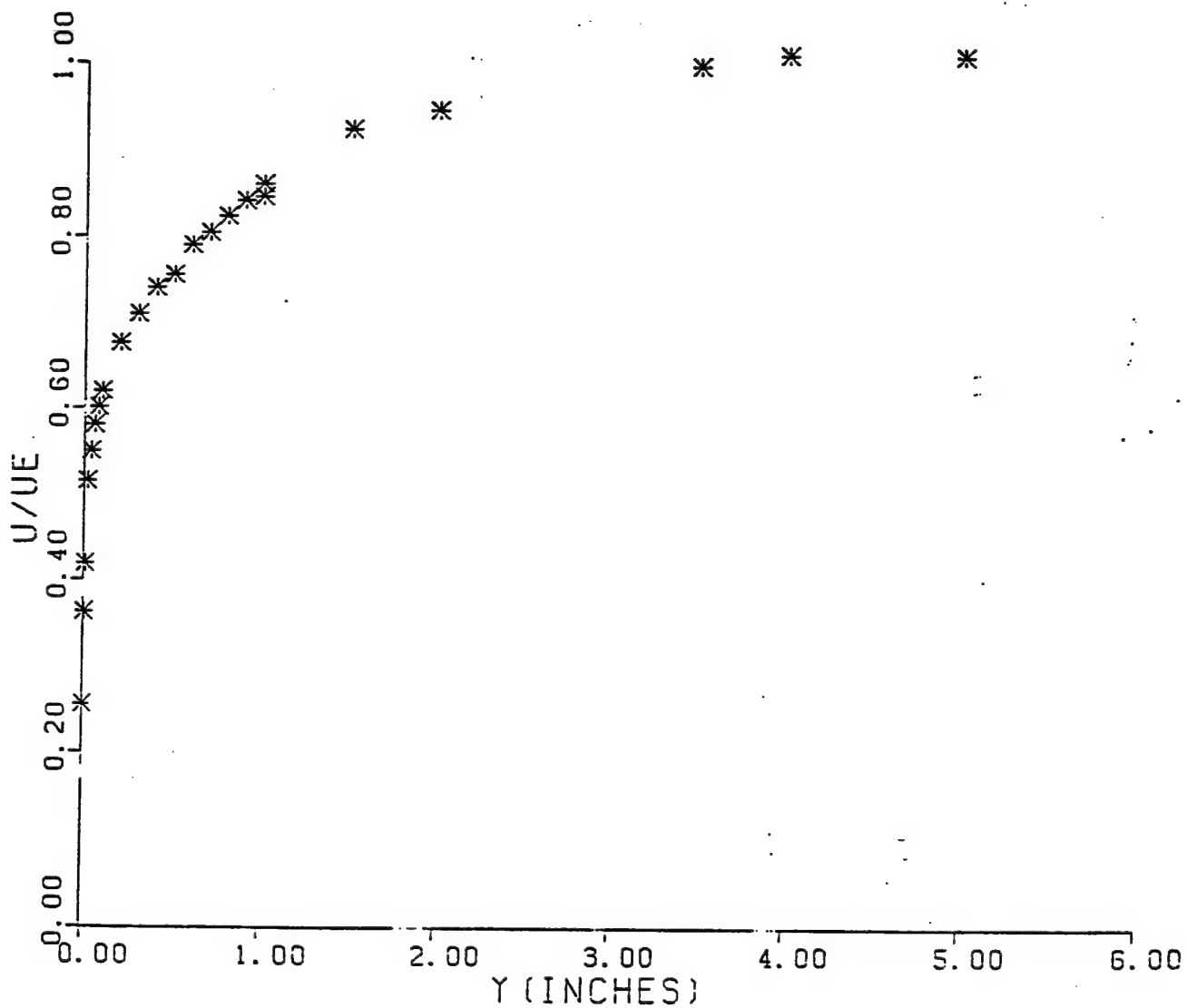
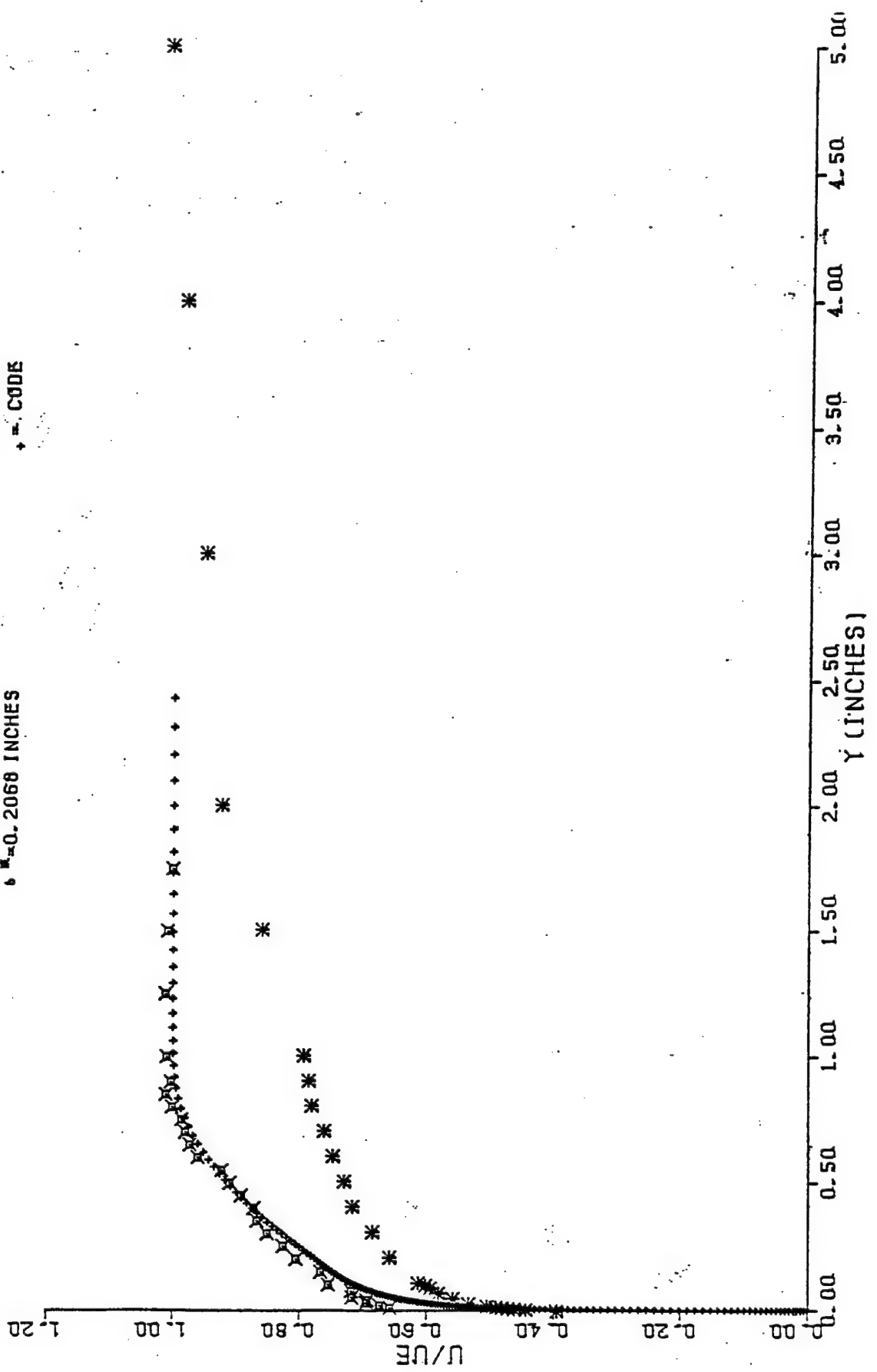


FIGURE 7. BOUNDARY LAYER SURVEYS

# TGF LV BOUNDARY LAYER SURVEY

X-STATION=87.75 MACH 0.30 Re=1.70 MILLION/FT Y-STATION=0.00

- \* = WOOD
- x = STEEL
- + = CODE



# TGF LV TURBULENCE INTENSITY

X-STATION=87.75 MACH= 0.30

STEEL	WOOD	ReN
0		1700000.0
+		1700000.0
	+	2000000.0

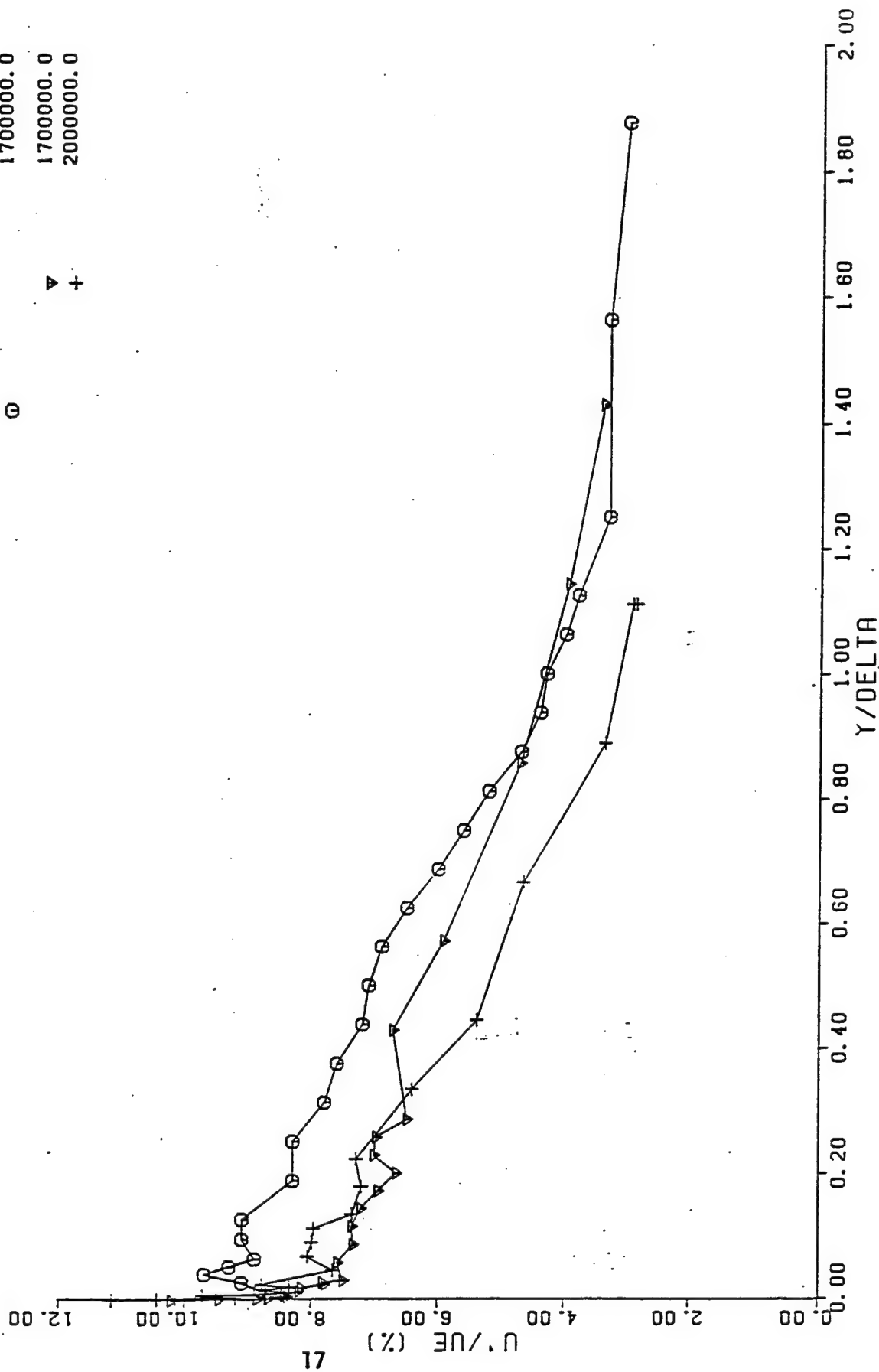
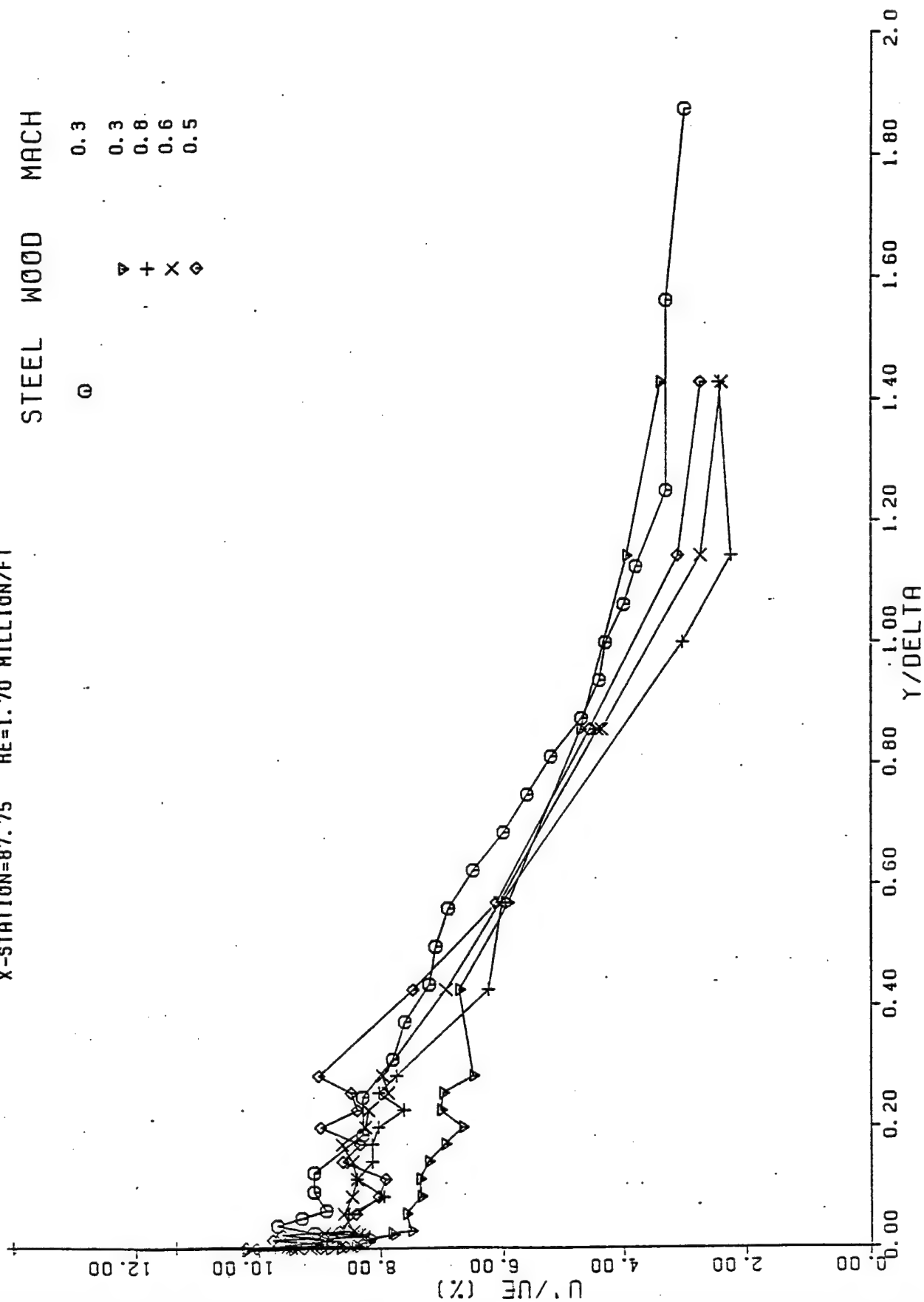


FIGURE 9. TURBULENCE INTENSITY

# TGF LV TURBULENCE INTENSITY

X-STATION=87.75 RE=1.70 MILLION/FT



# TGF FREE STREAM

MACH 0.8 CENTER LINE

U-COMPONENT LV DATA

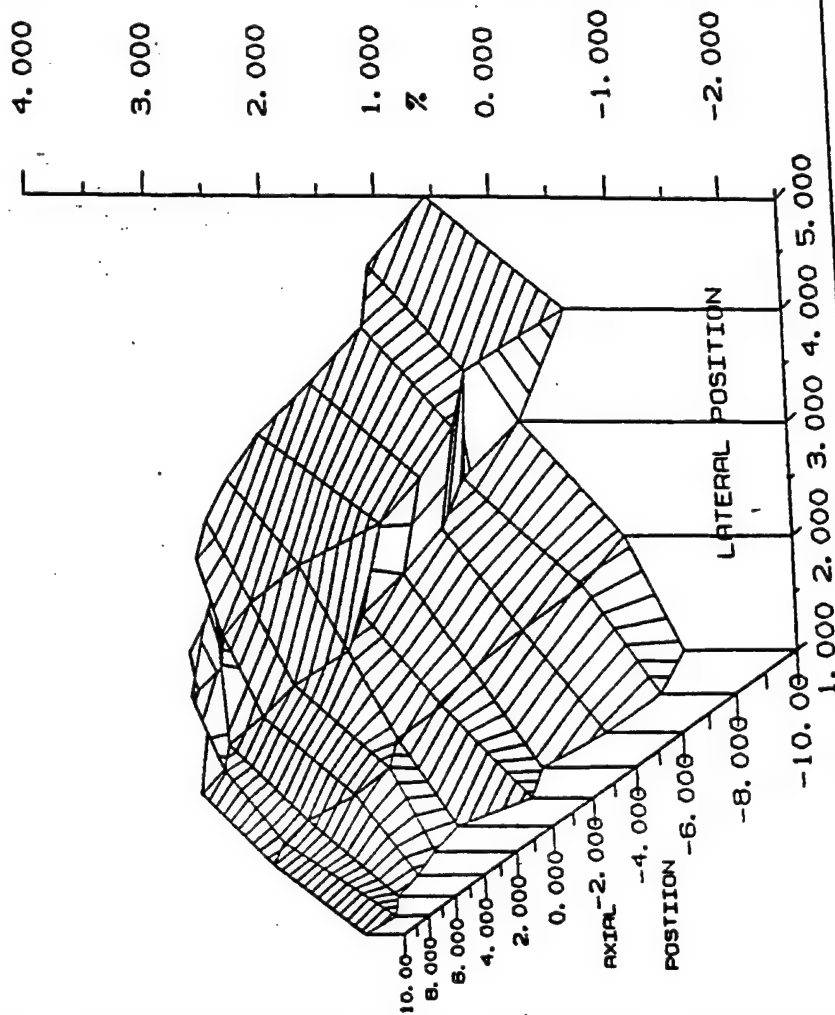


FIGURE 11. FREE STREAM CONTOURS

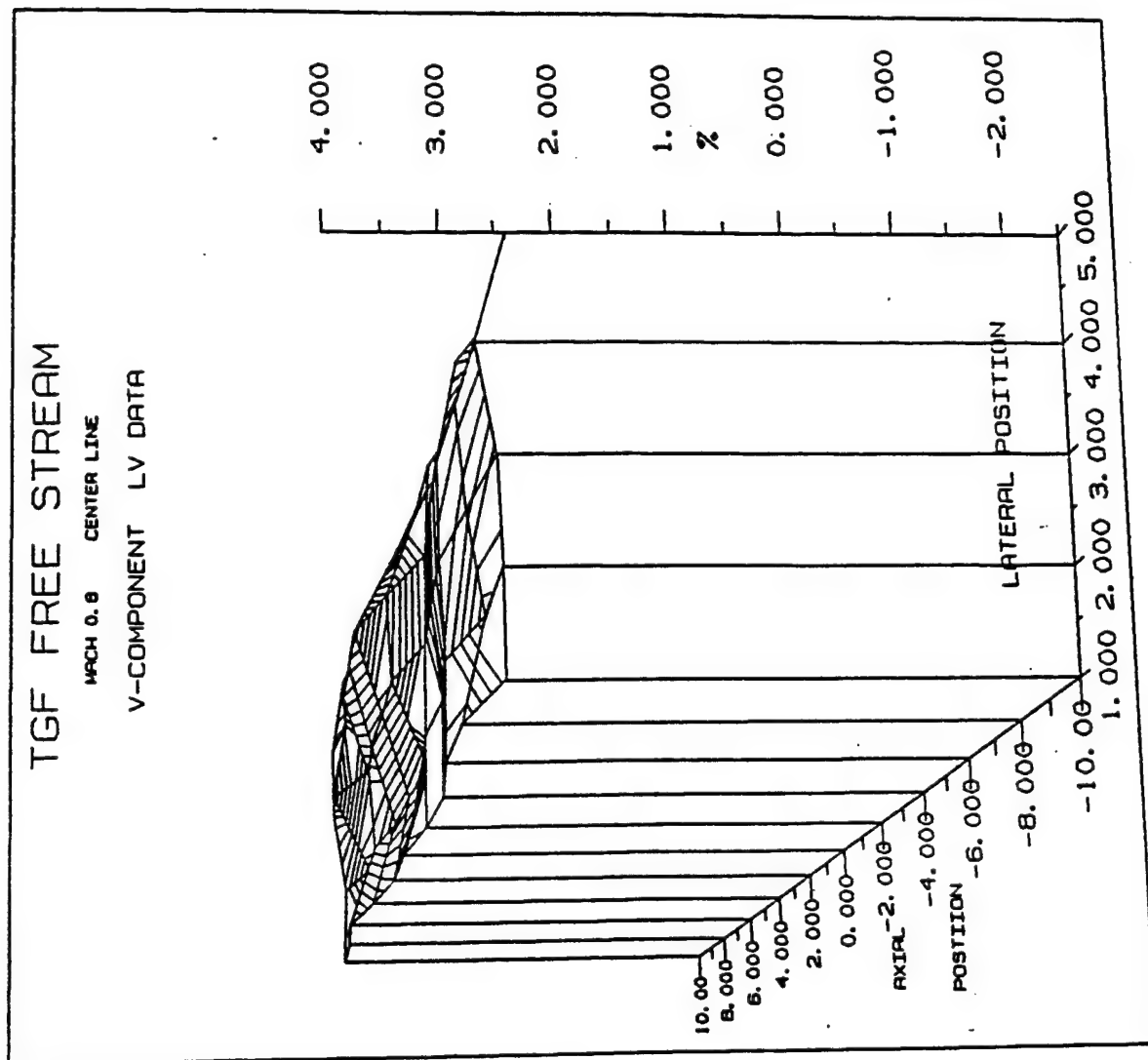


FIGURE 12. FREE STREAM CONTOURS



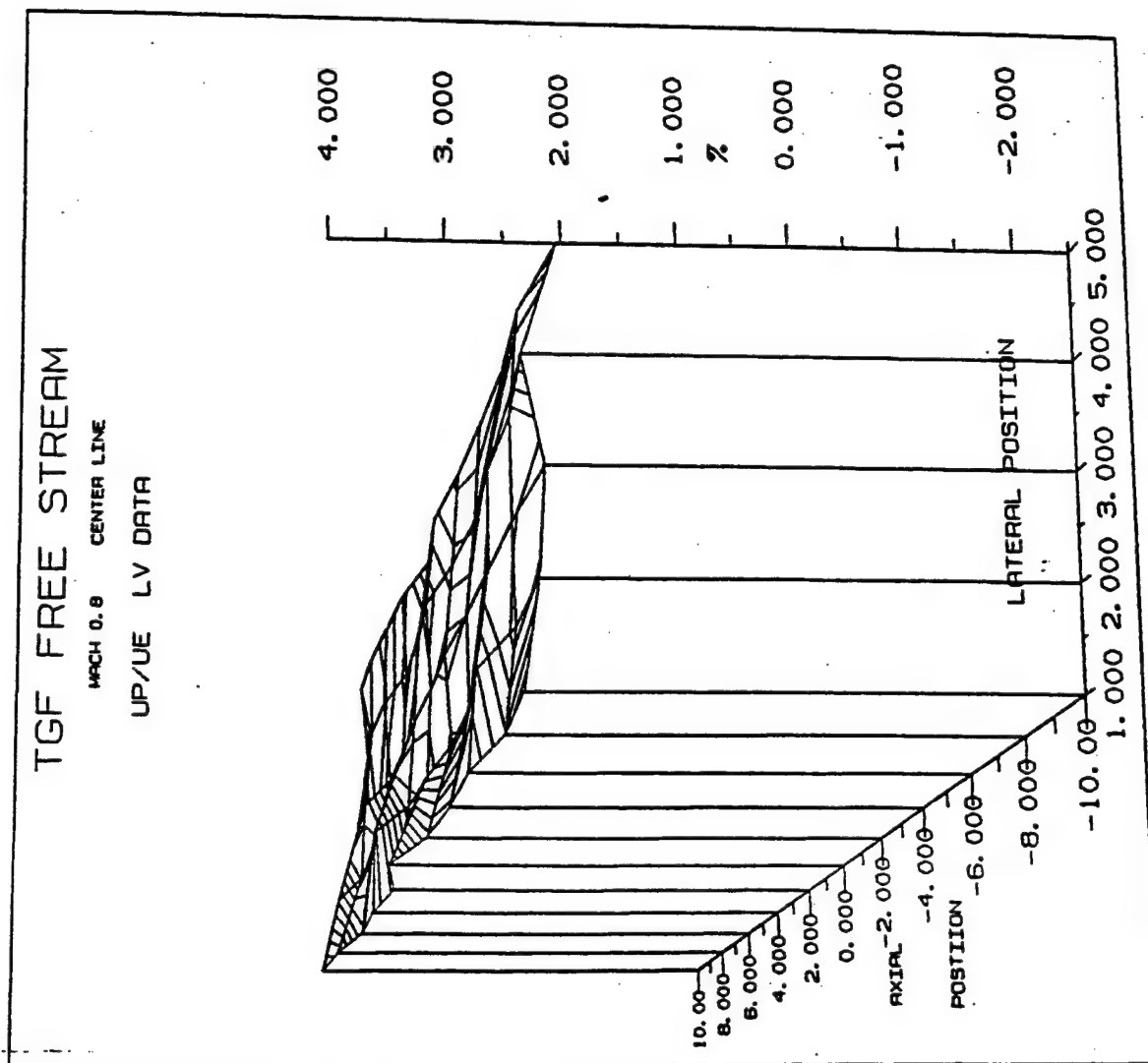


FIGURE 13. FREE STREAM CONTOURS

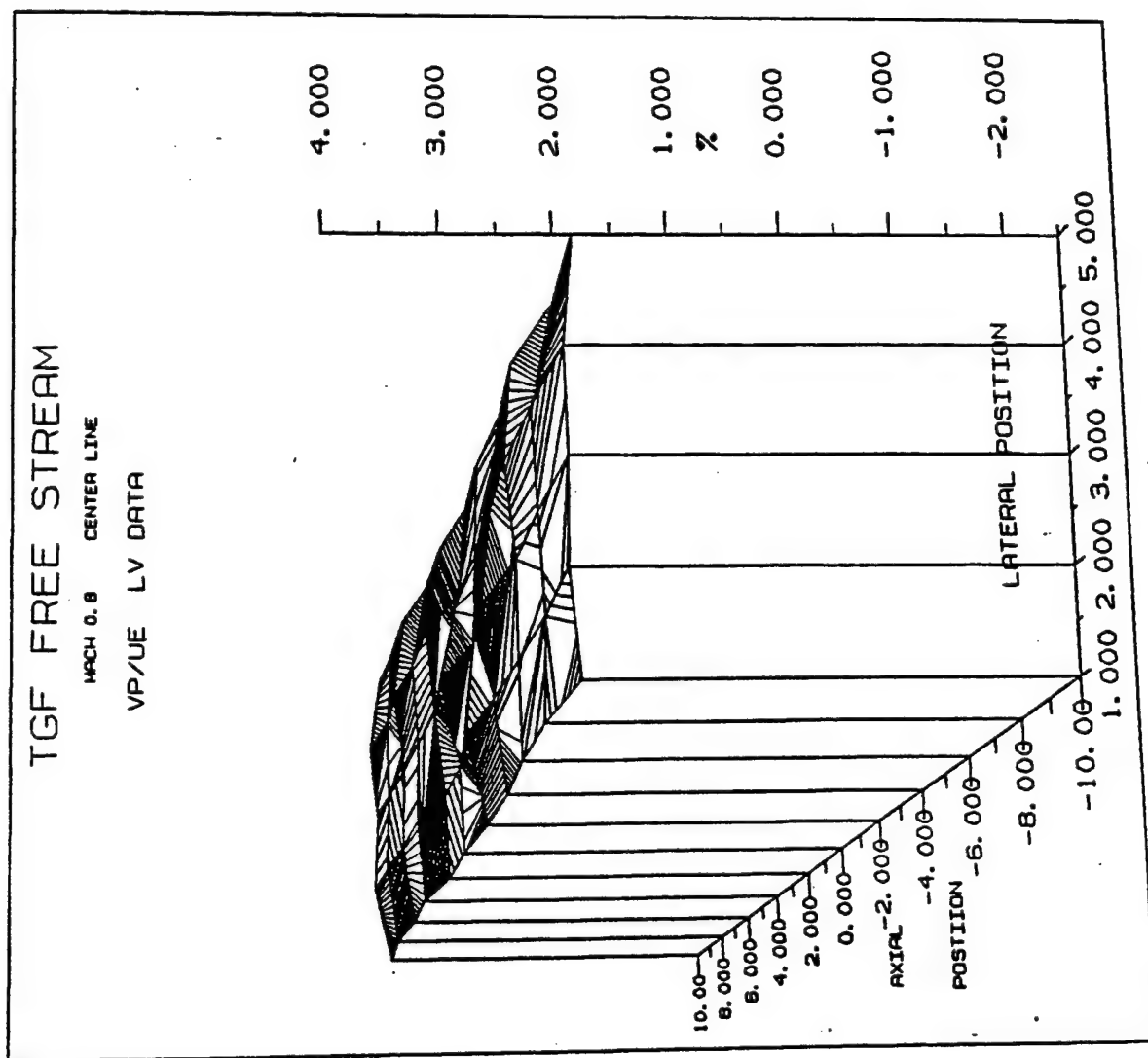


FIGURE 14. FREE STREAM CONTOURS

# TGF FREE STREAM

MACH 0.8 CENTER LINE +1

U-COMPONENT LV DATA

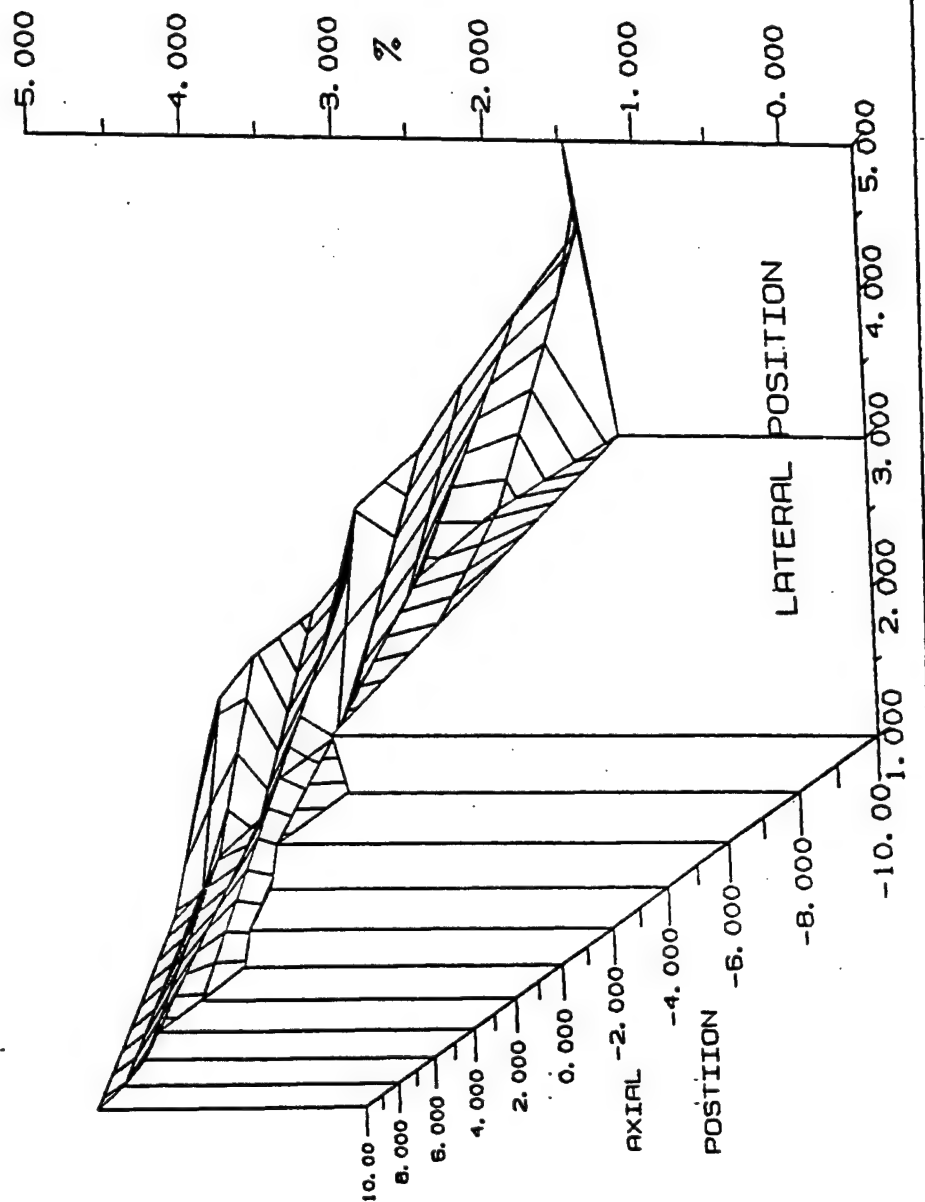


FIGURE 15. FREE STREAM CONTOURS

# TGF FREE STREAM

MACH 0.8 CENTER LINE +1

V-COMPONENT LV DATA

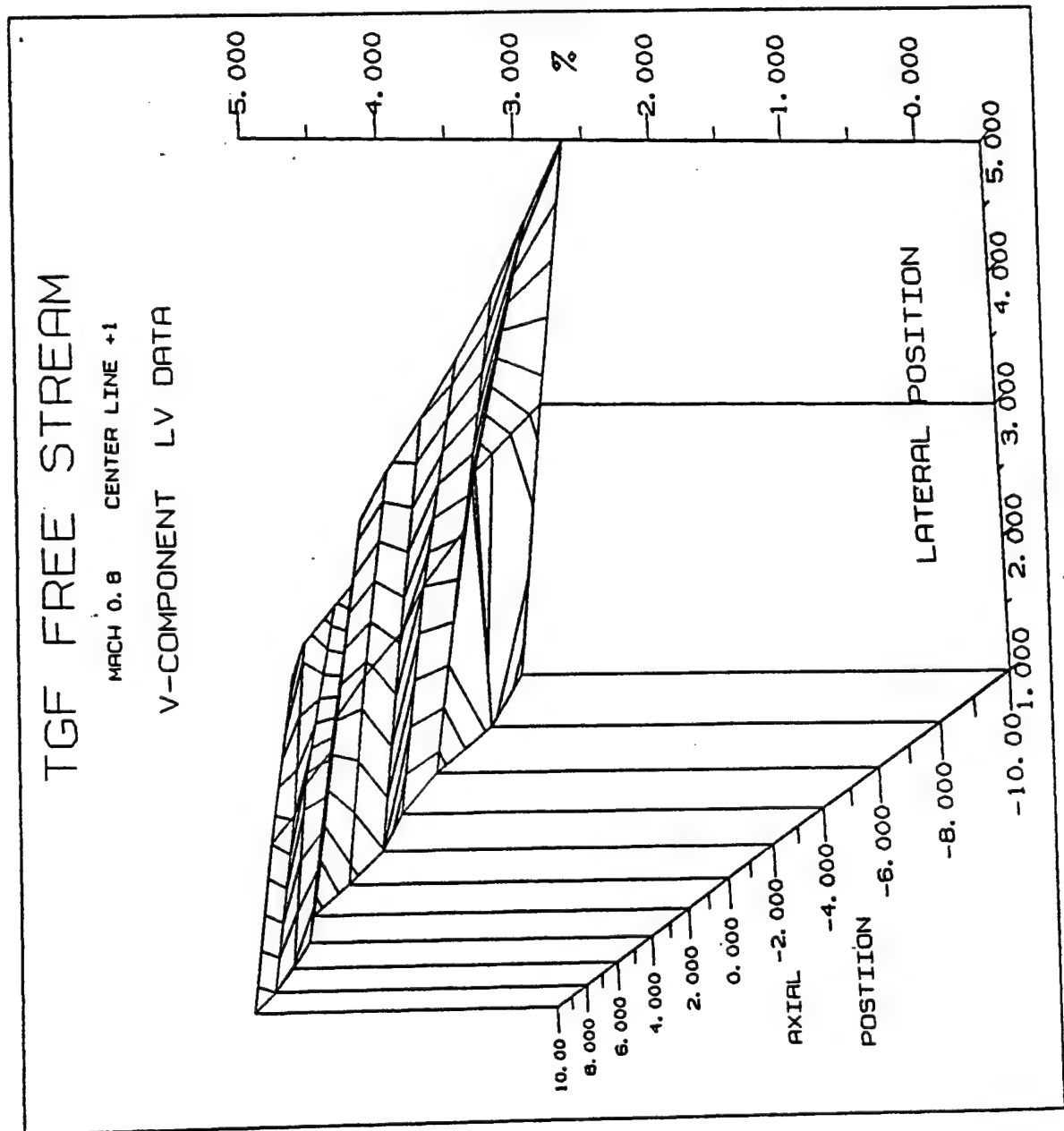


FIGURE 16. FREE STREAM CONTOURS

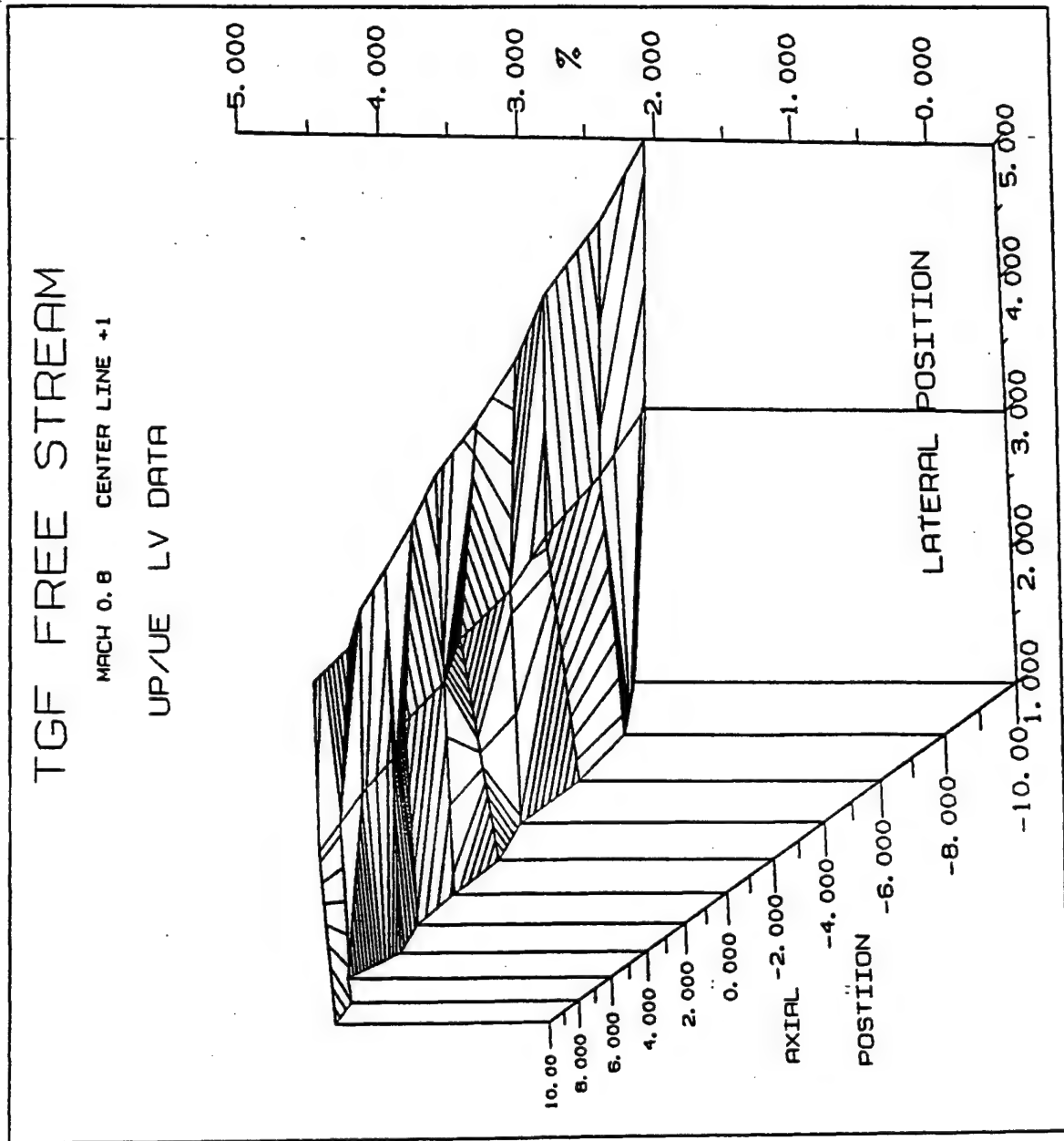


FIGURE 17. . FREE STREAM CONTOURS

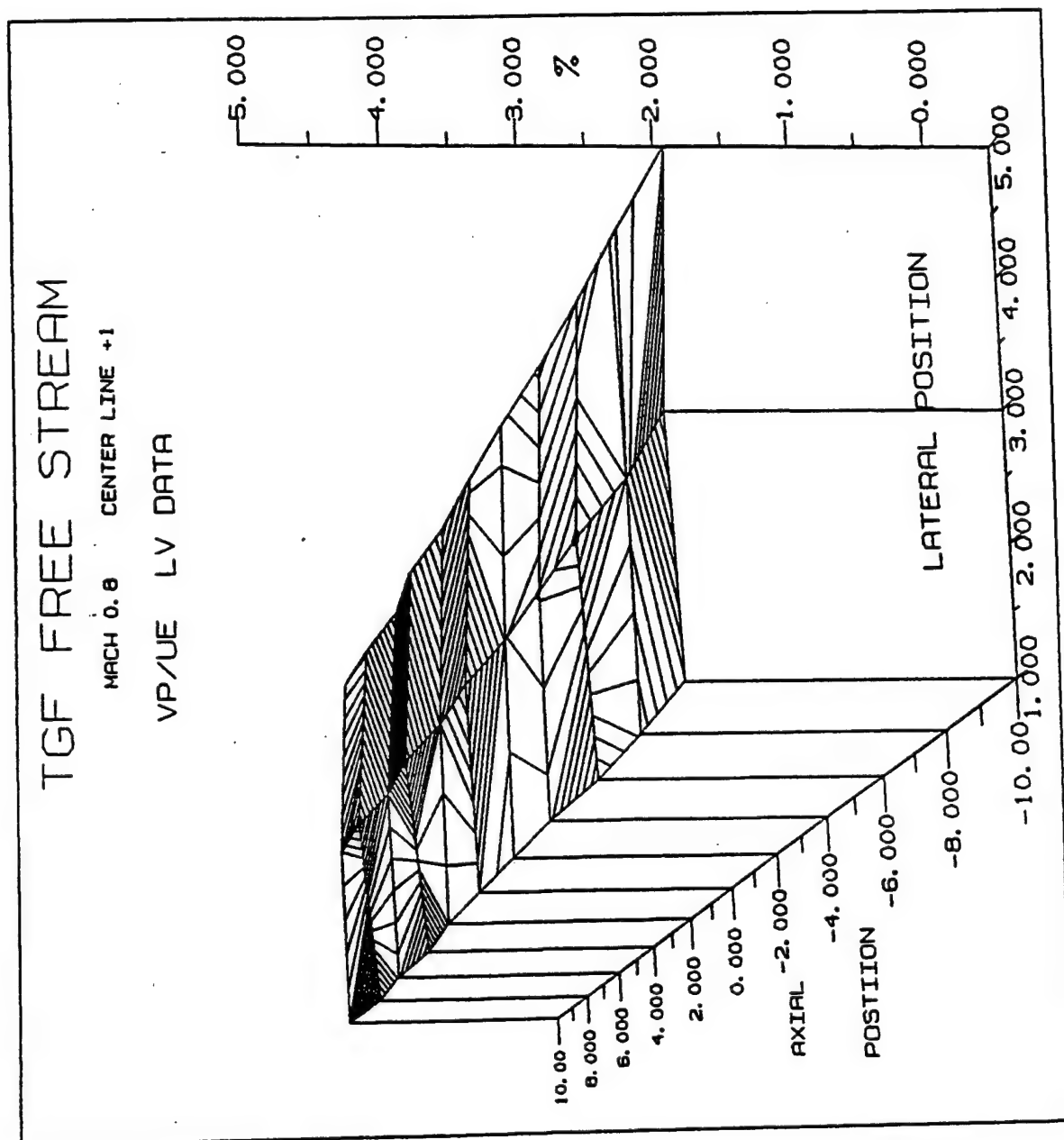


FIGURE 18. FREE STREAM CONTOURS

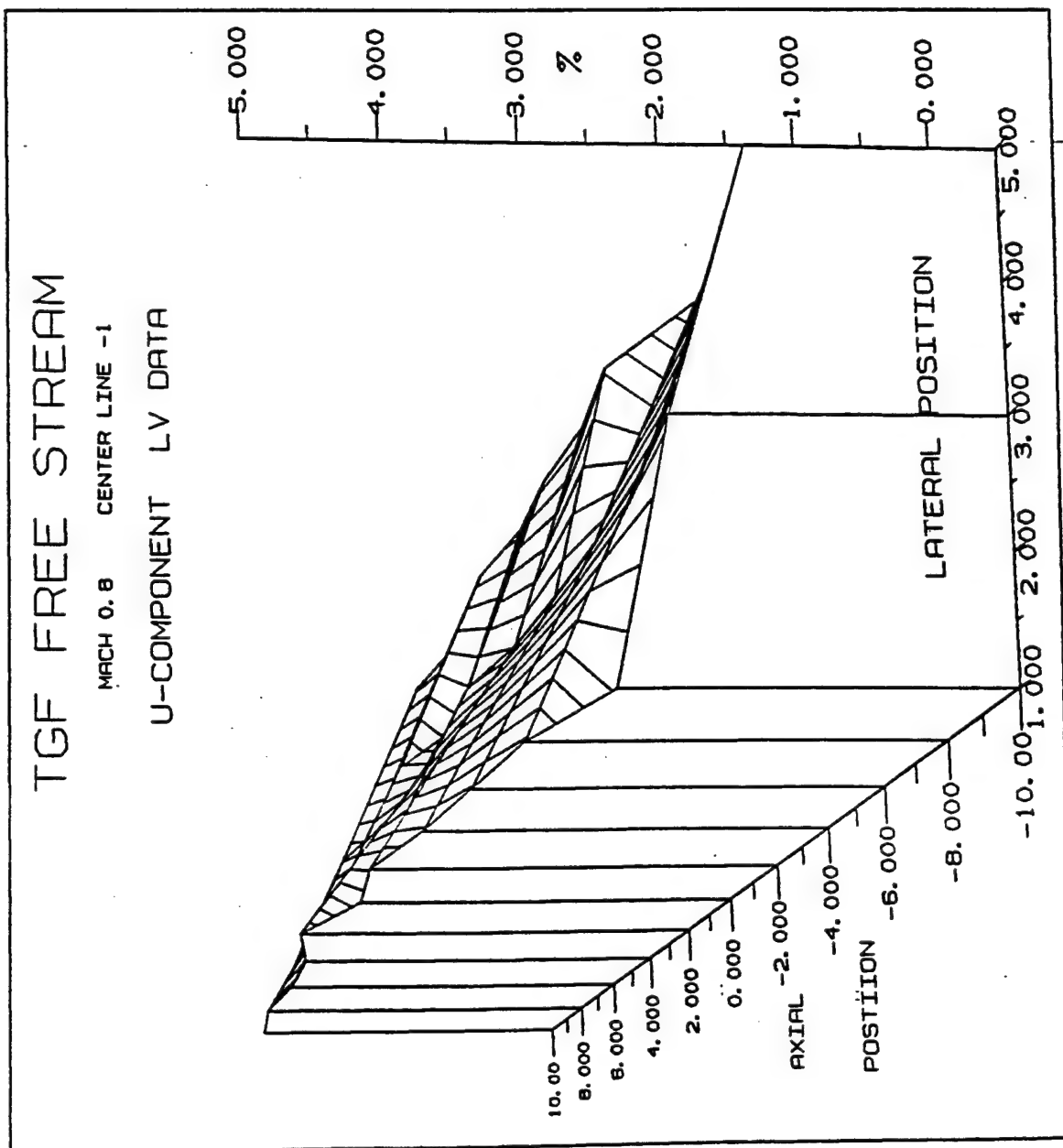


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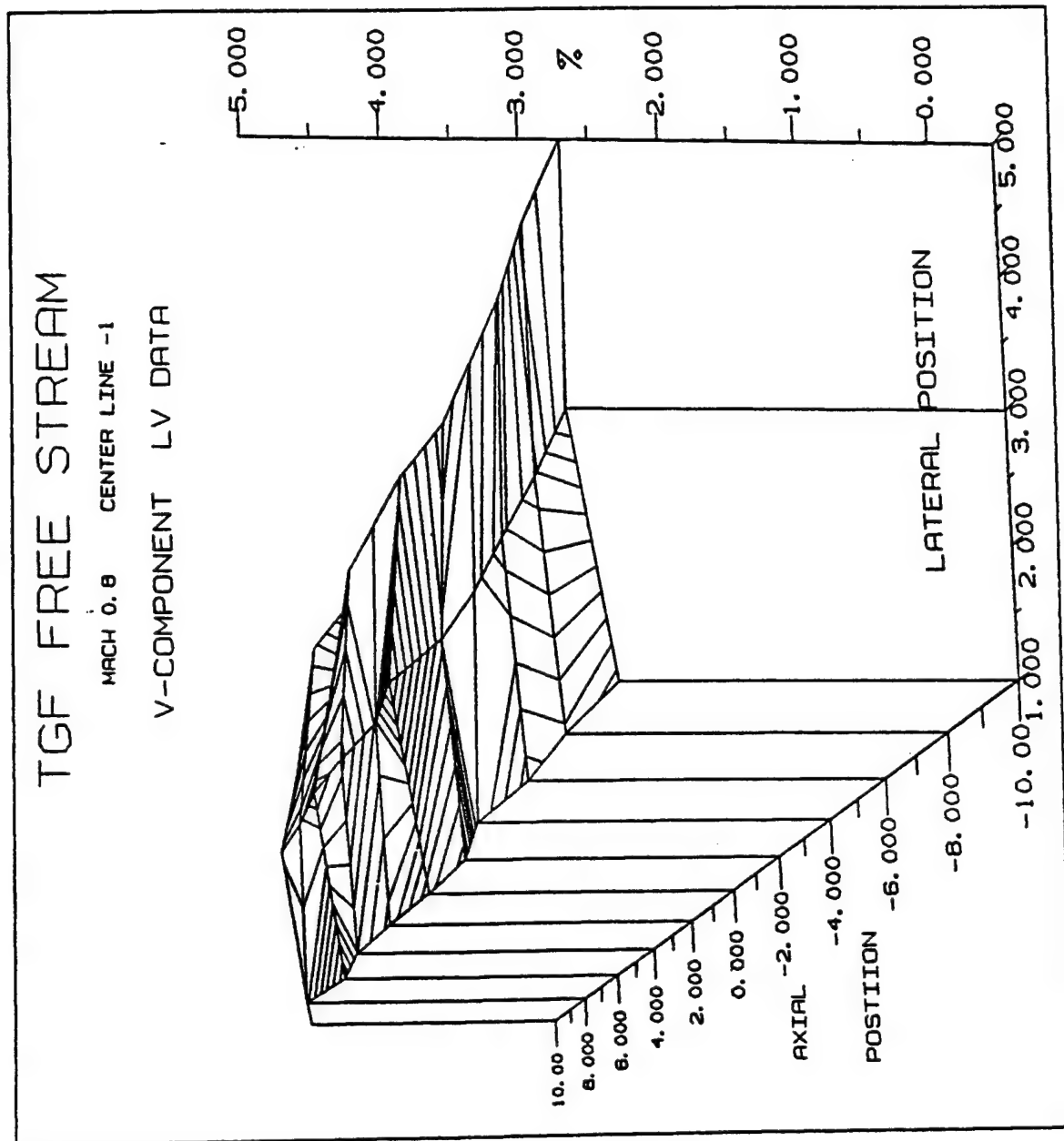


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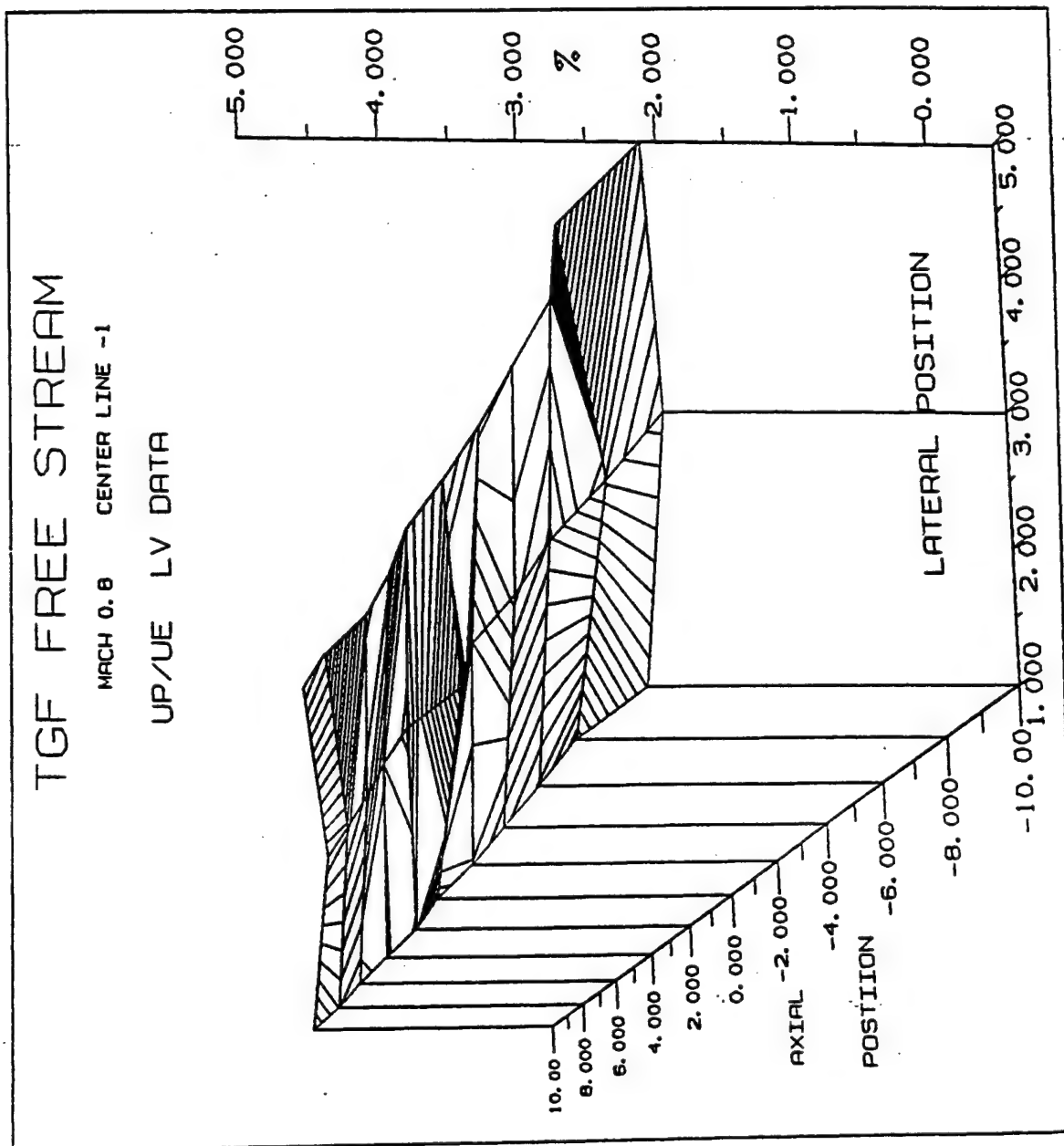


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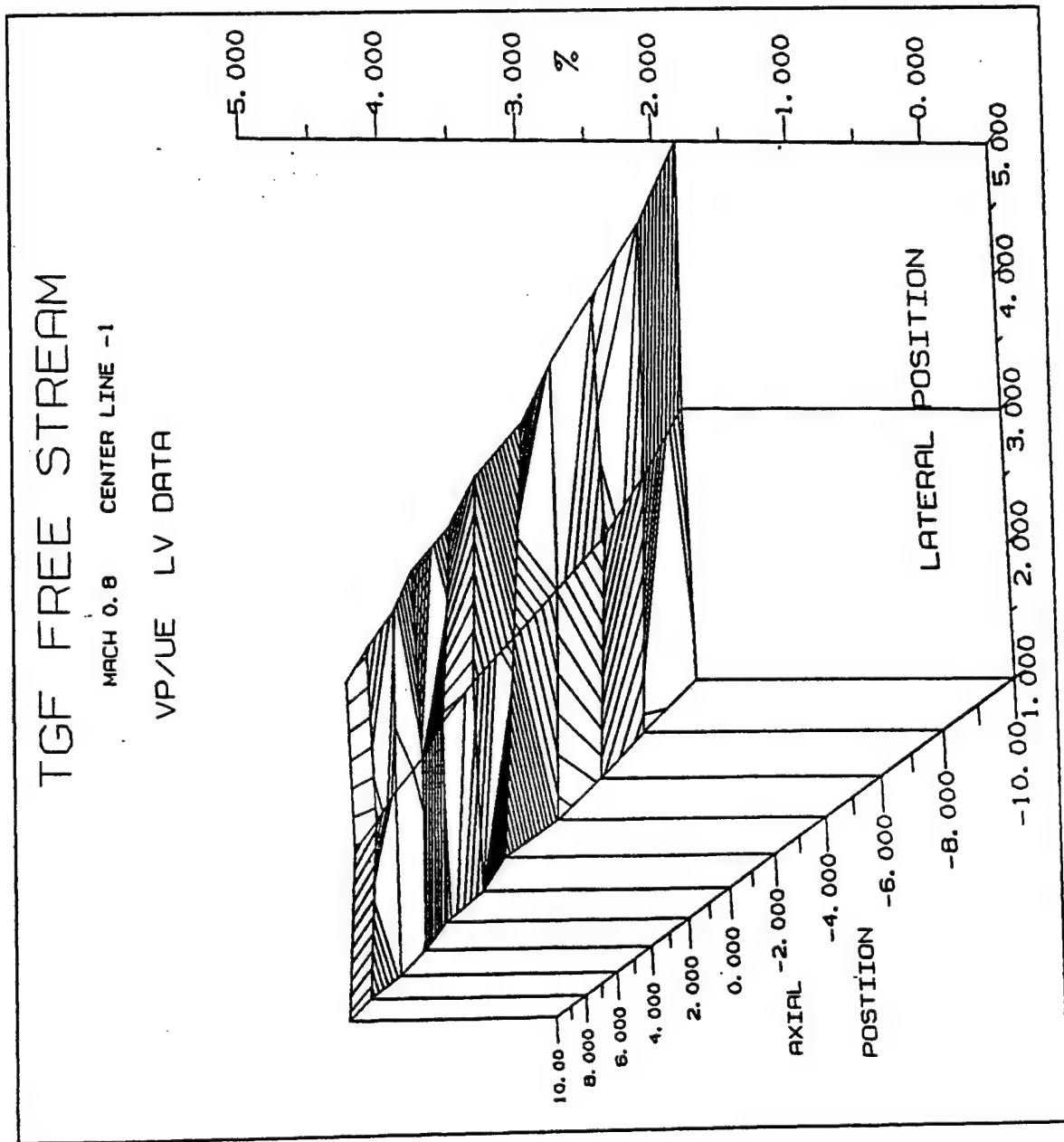


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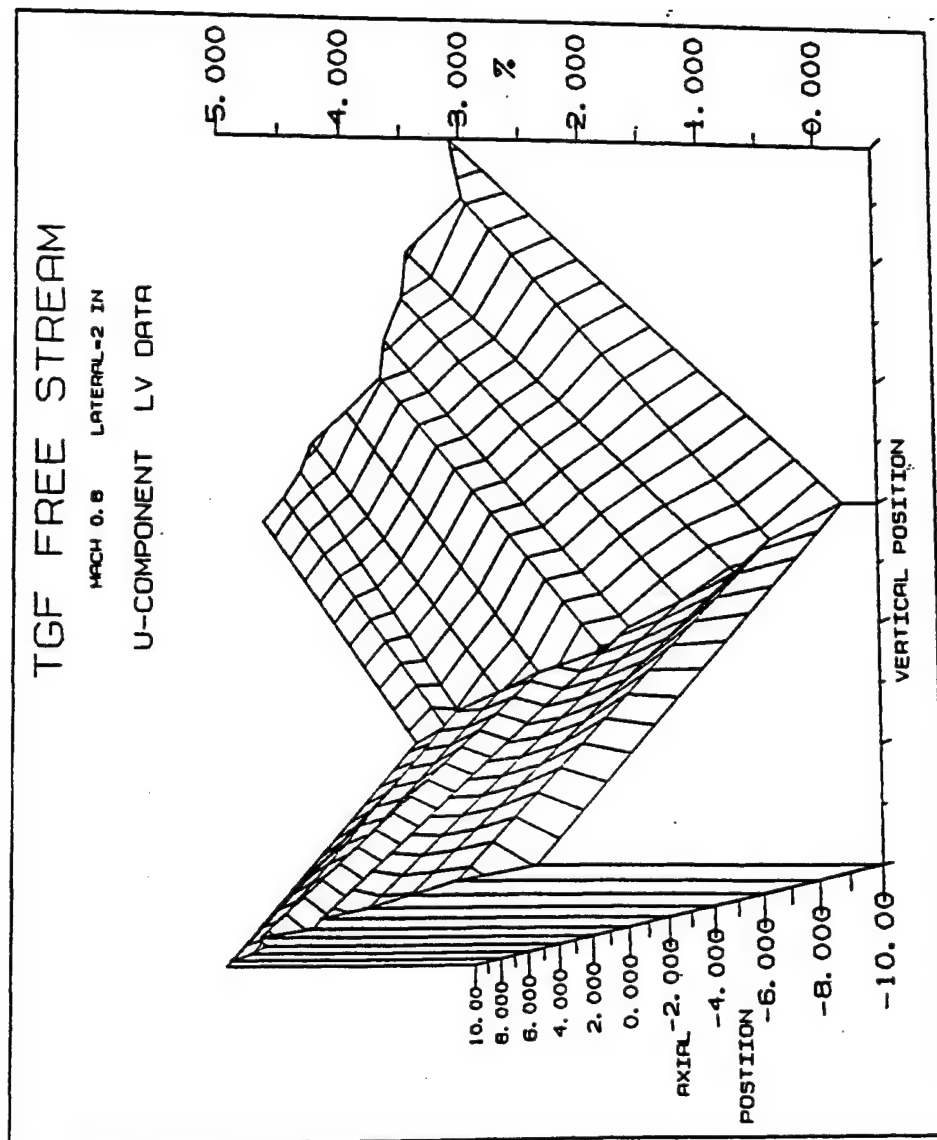


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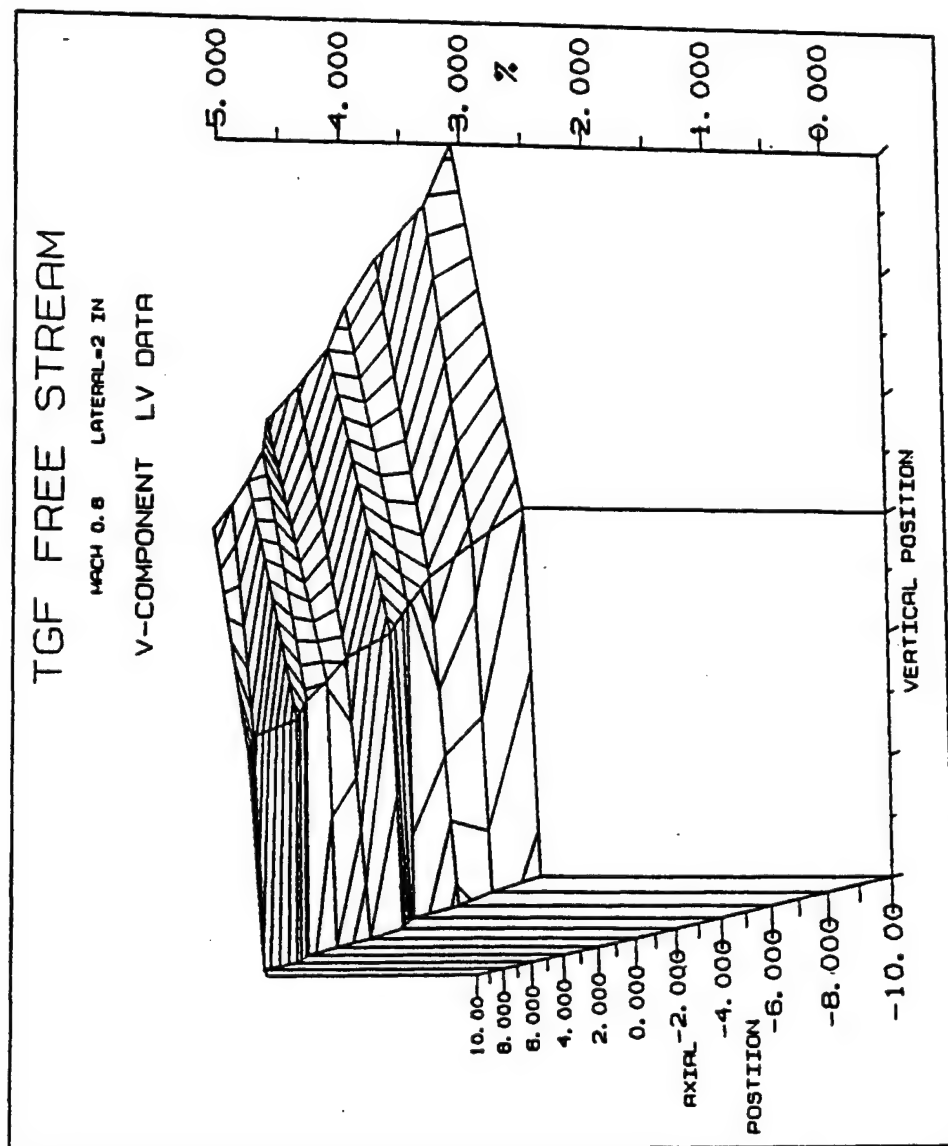


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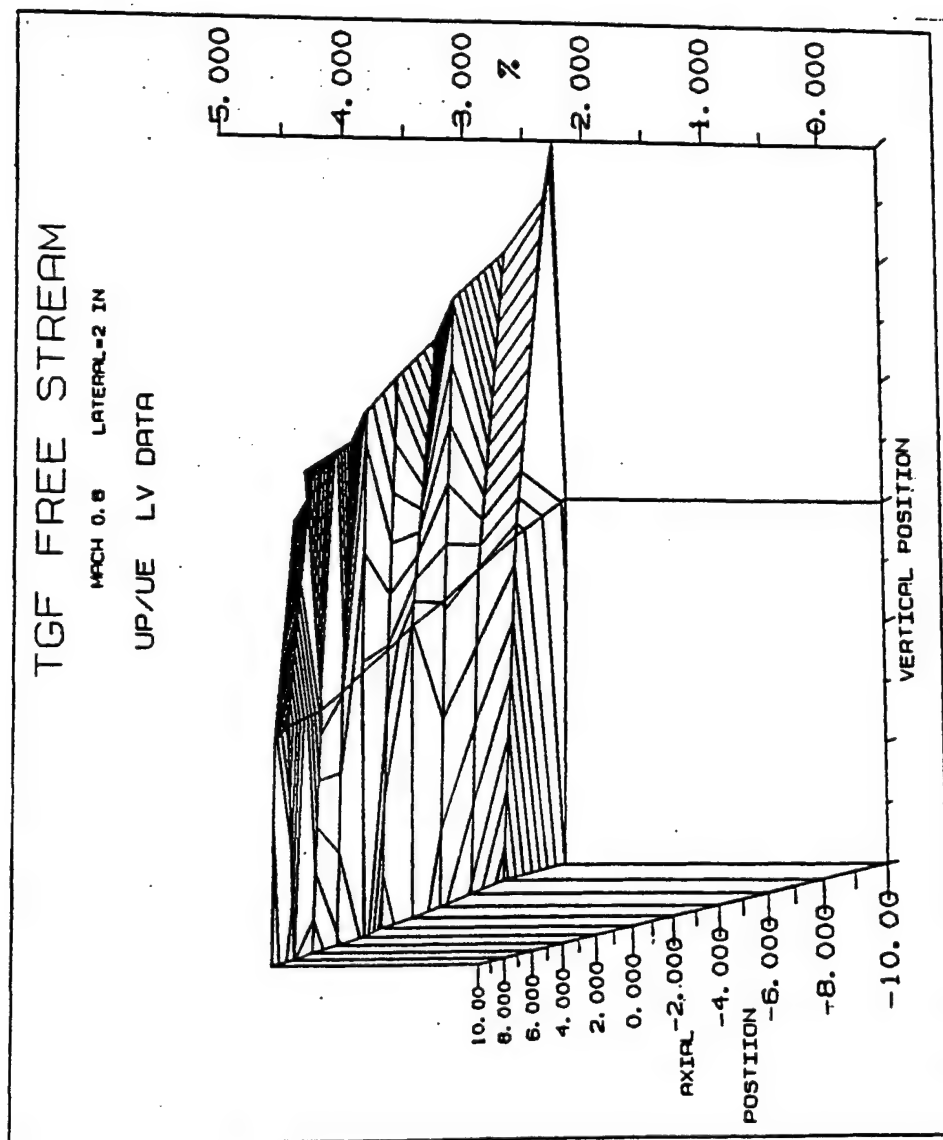


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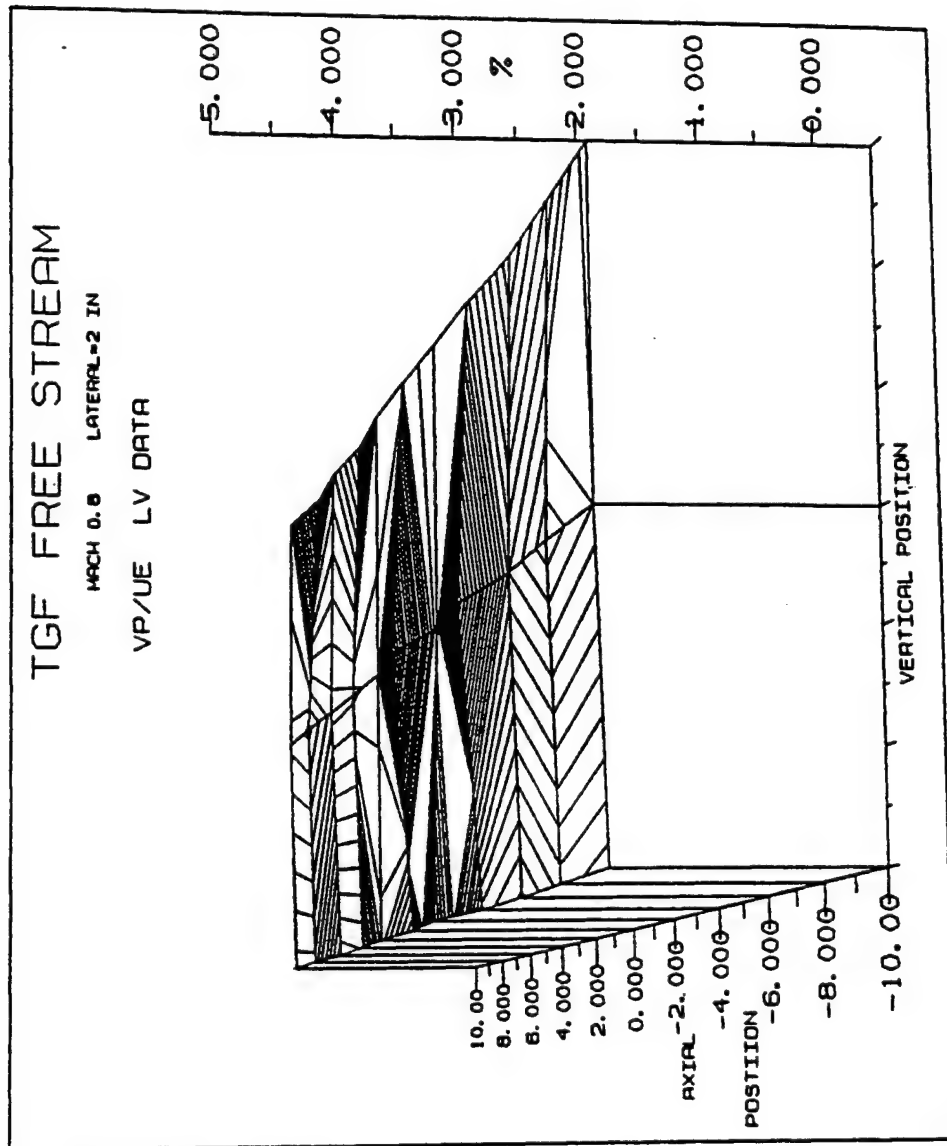


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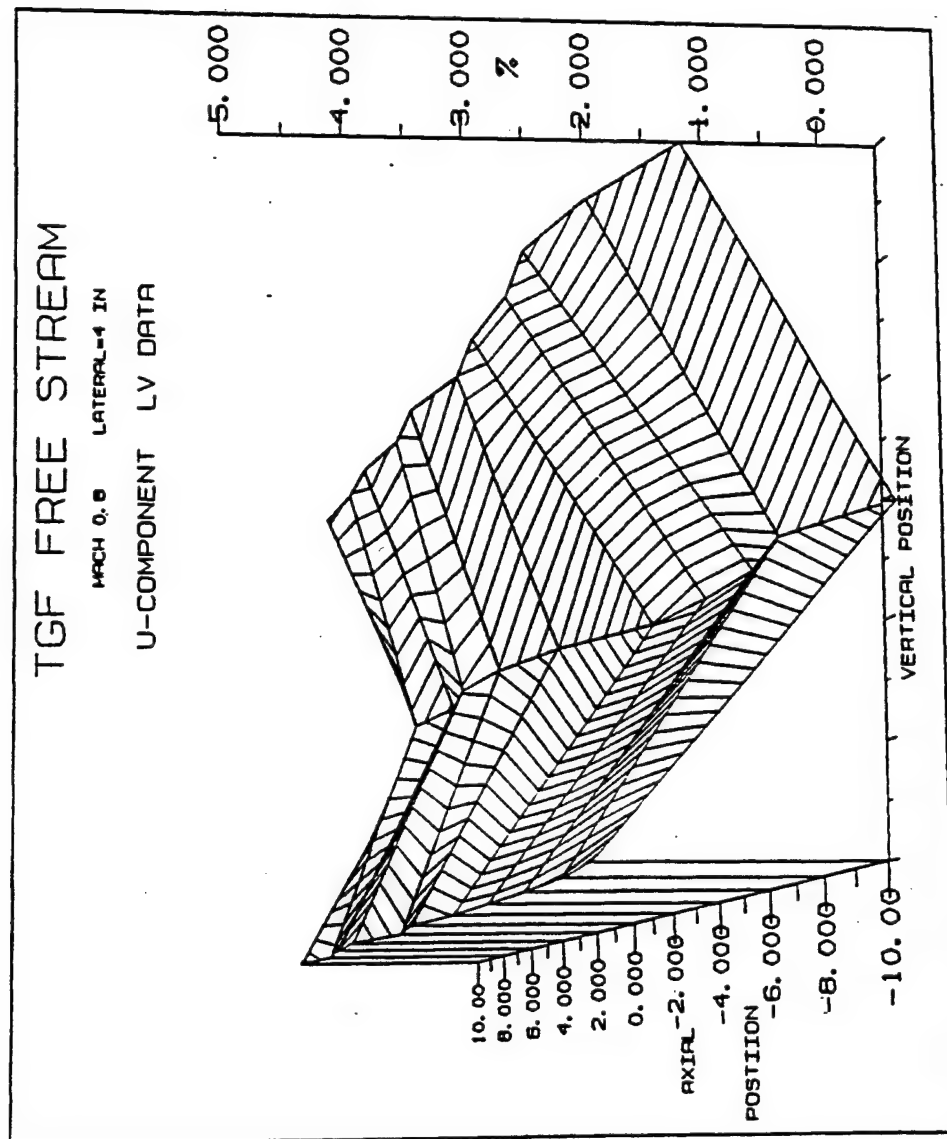


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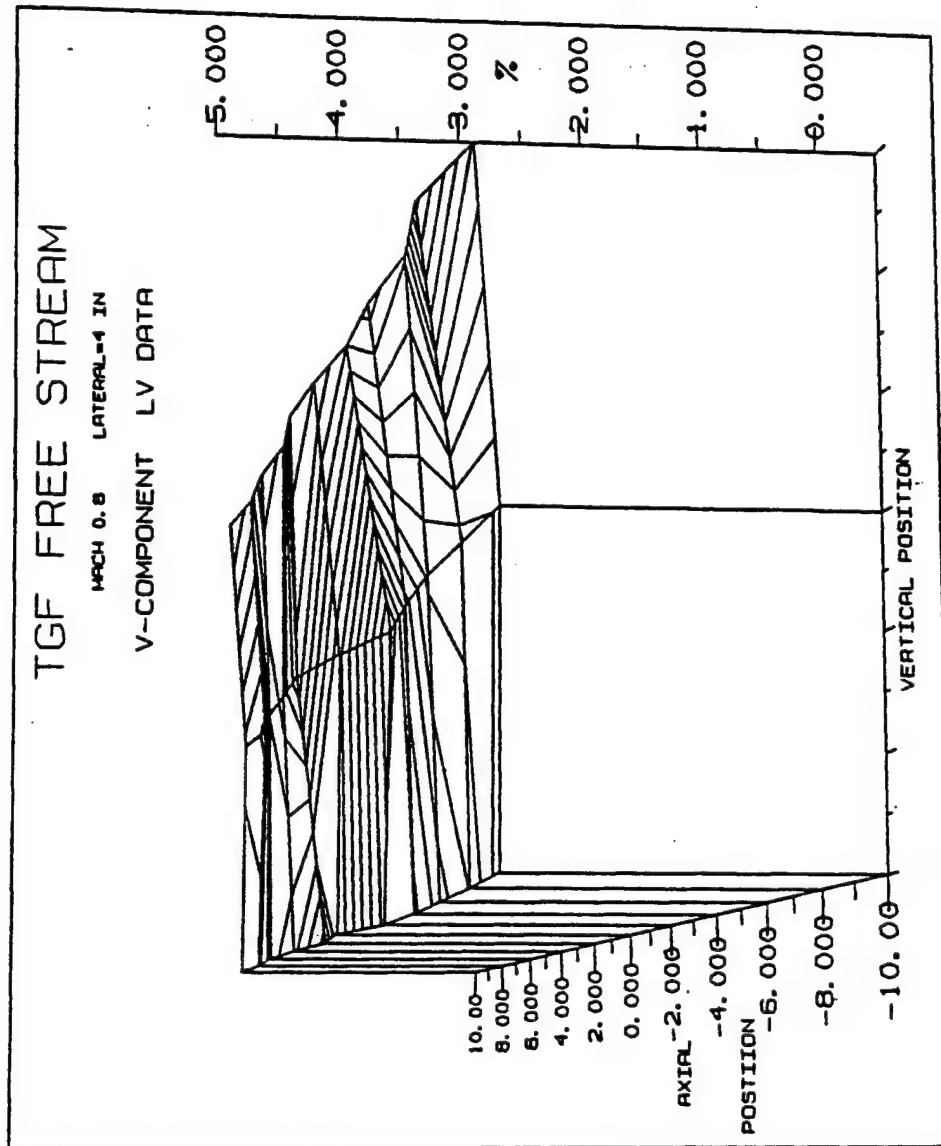


FIGURE 28. FREE STREAM CONTOURS



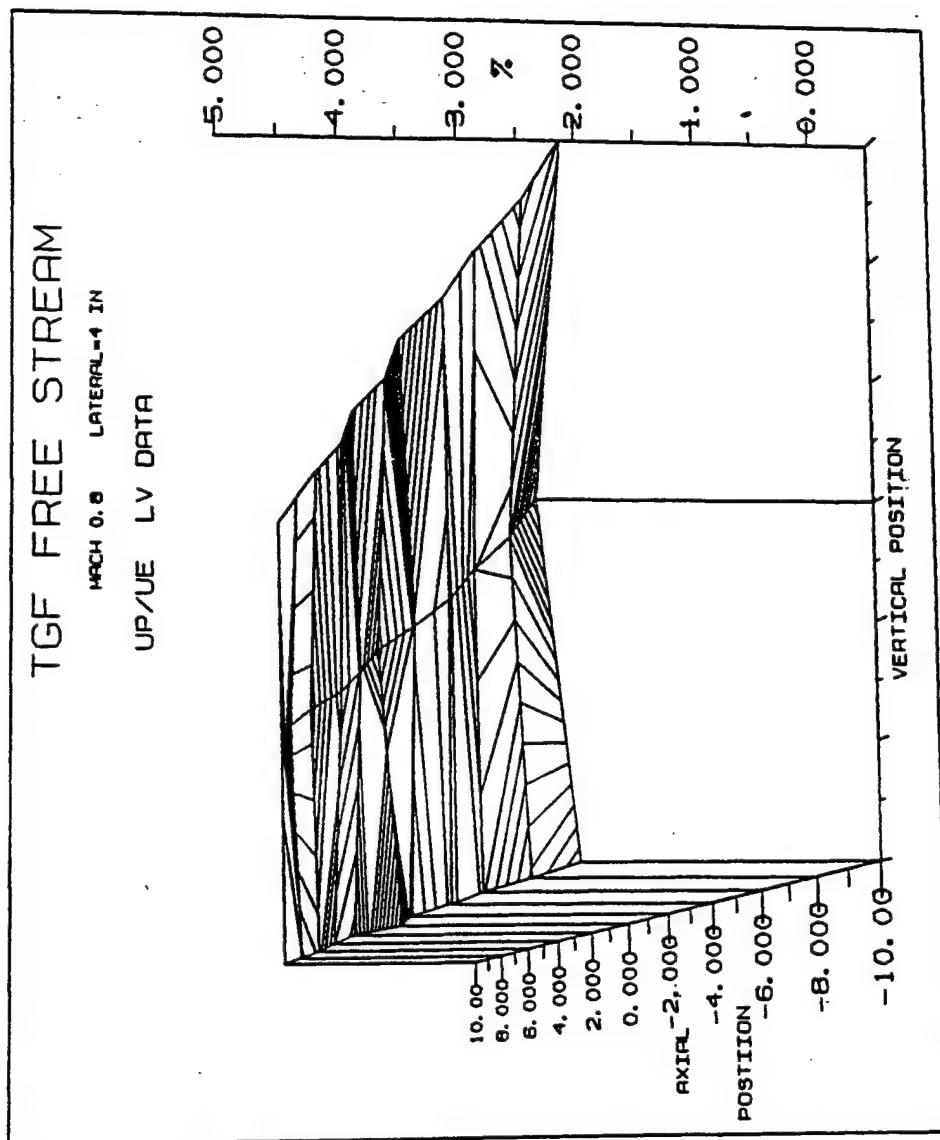


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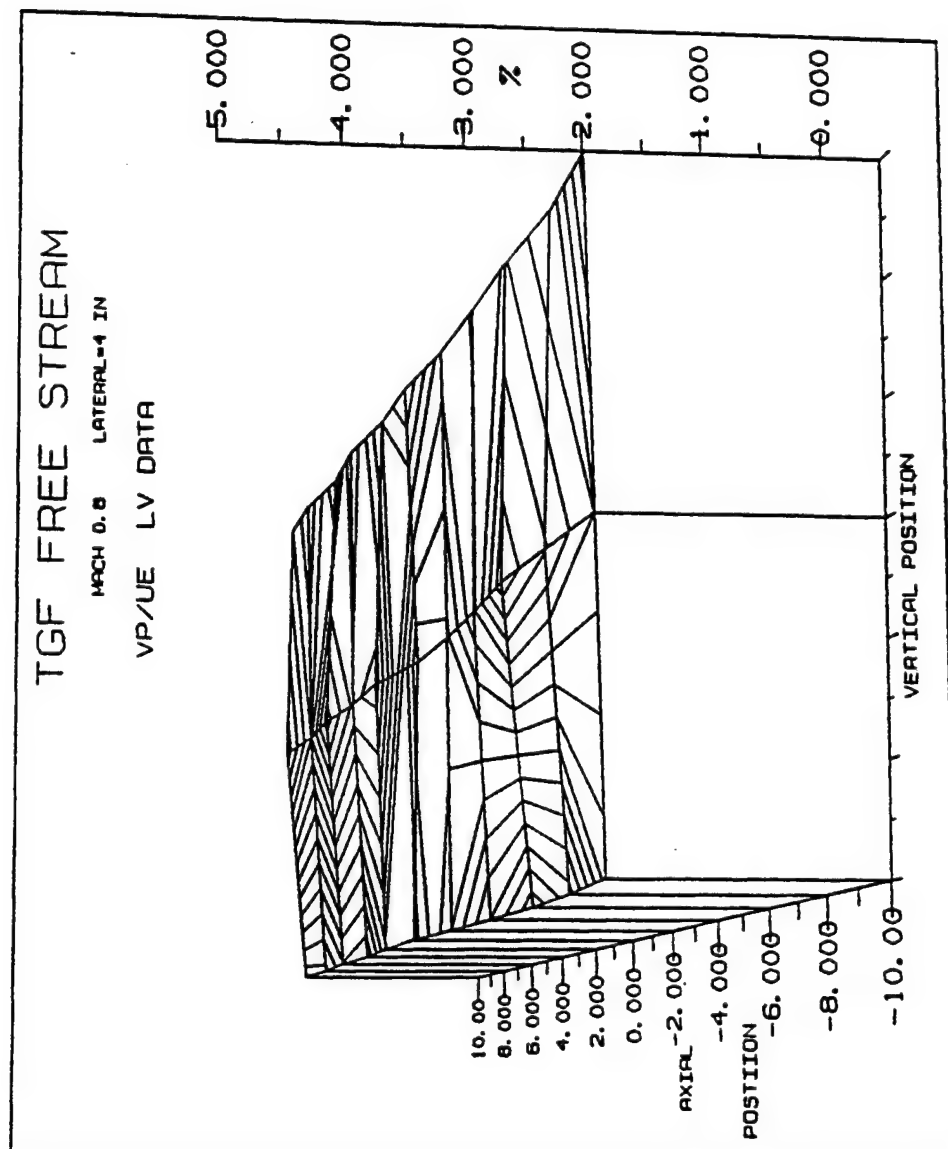


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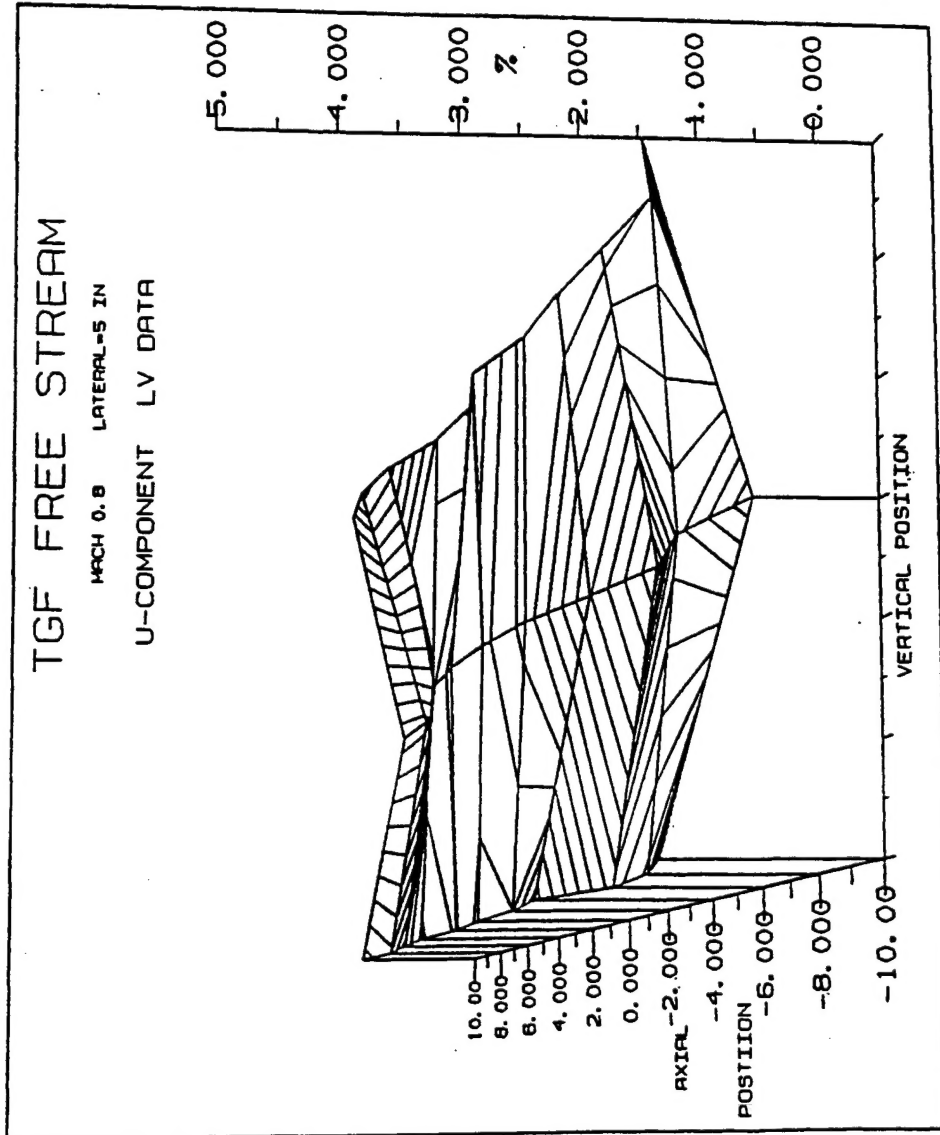


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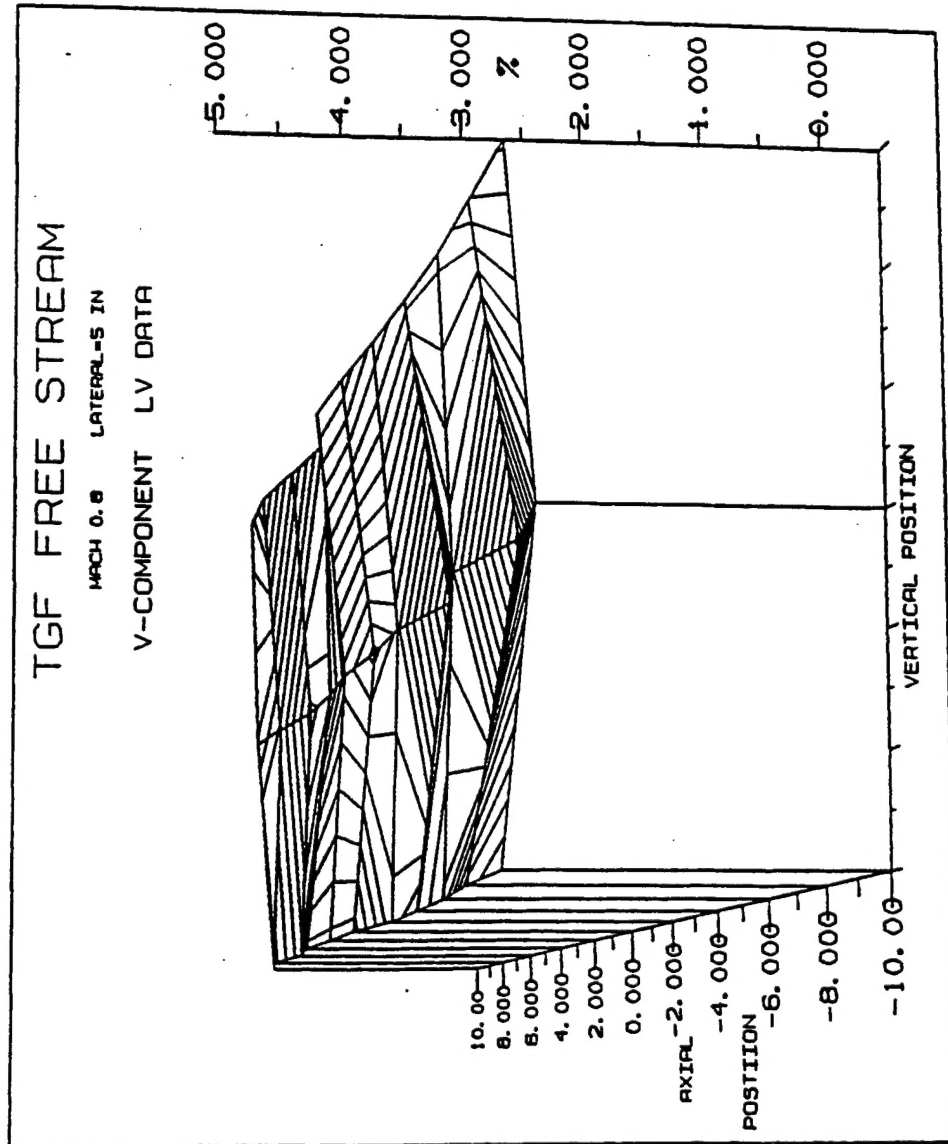


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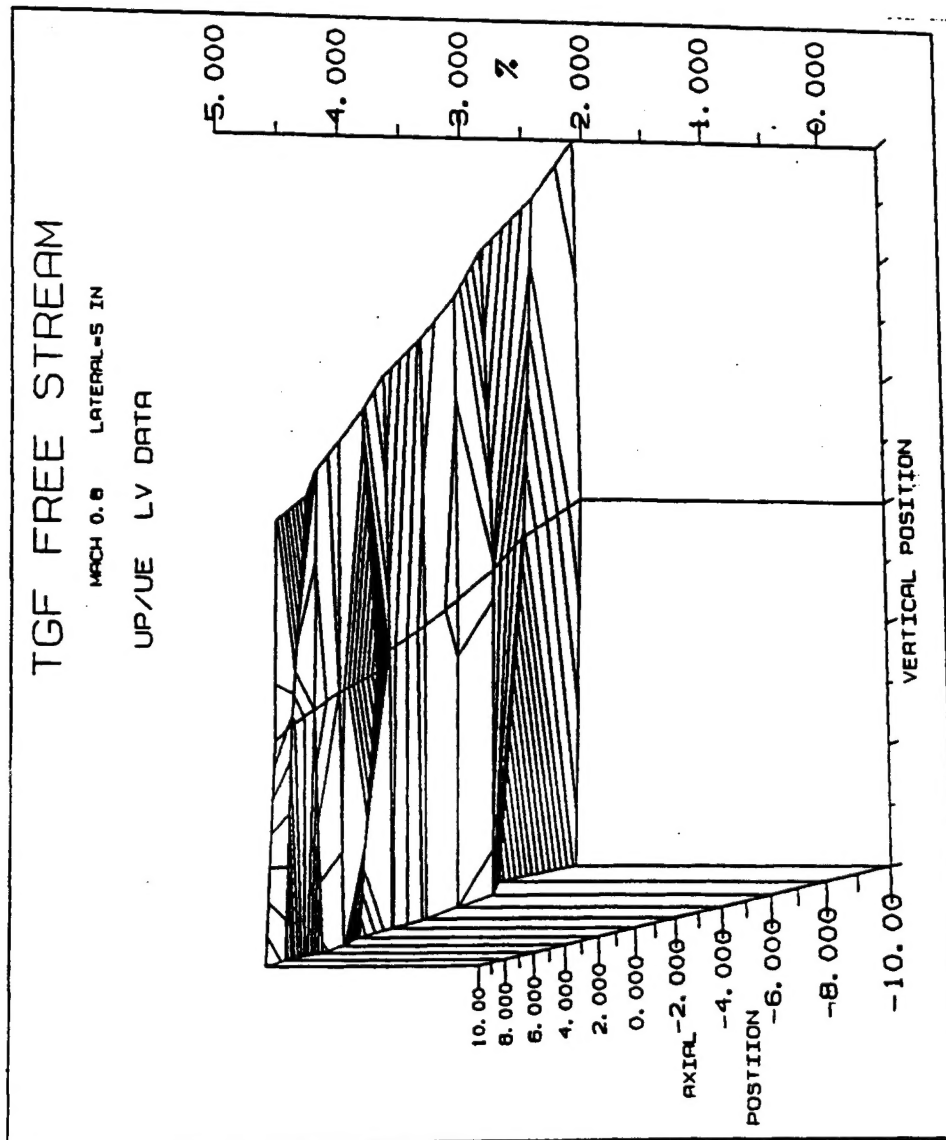


FIGURE 33. FREE STREAM CONTOURS

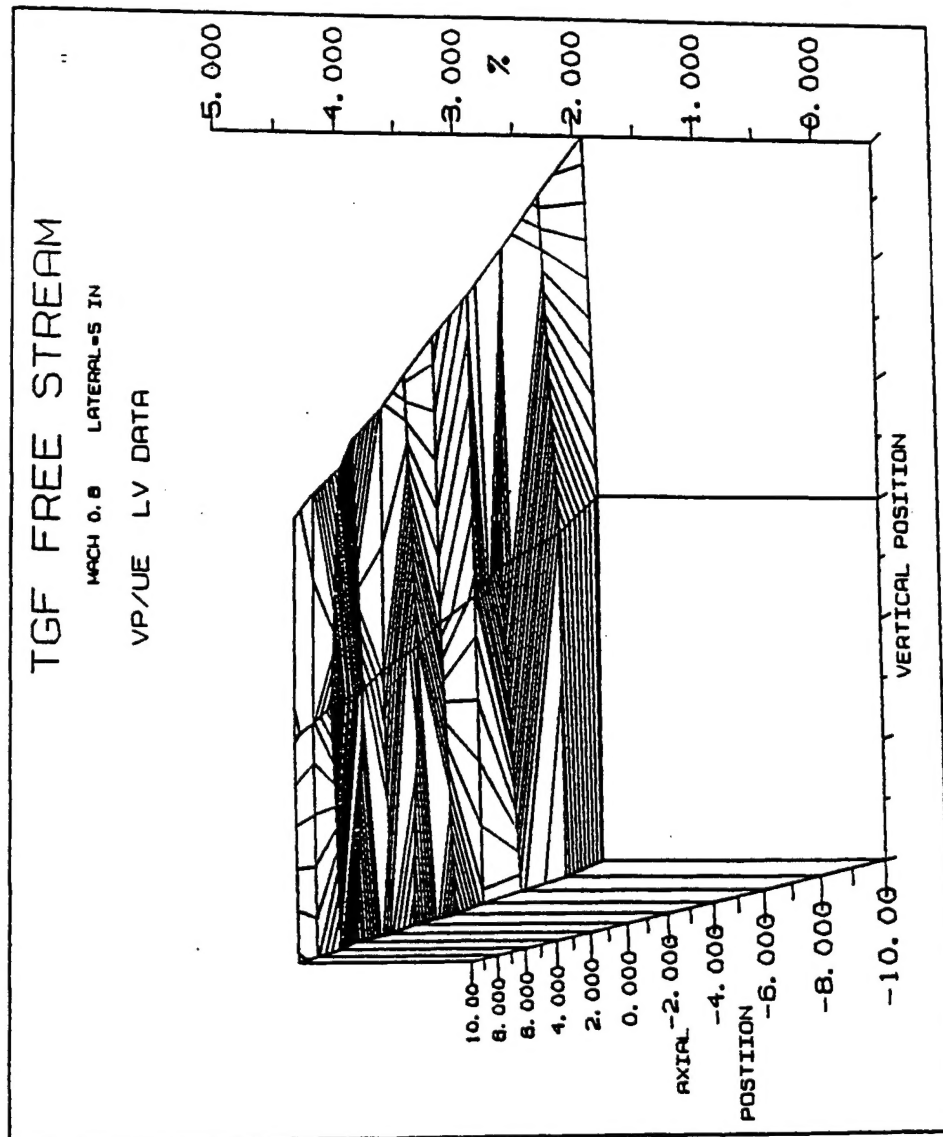


FIGURE 34. . FREE STREAM CONTOURS